National Aeronautics and Space Administration

NASA

LASER COMMUNICATIONS RELAY DEMONSTRATION

bridging the gap to the next era of space communications

A dual format optical communication modem development for the Laser Communica[…] Relay Demonstra[…] (LCRD) Progra[…]

October 1st, 2012

How Much we can talk about MITLL DPSK Modem?

- Jason Badgley
- Richard Butler
- Mike Krainak
- Steve Li
- Ed Luzhansky
- Scott Merritt
- Anthony Yu

Agenda

- Overview of the Laser Communication Activities at Goddard Space Flight Center
- LCRD Program Overview
- Laser Communication Transceivers Demonstrations
- Dual Modulation Format Transceiver Development
- Summary and Path Forward

NASA-GSFC's heritage of space laser communications dates back to 1960s

YEAR	SATELLITE	METHOD	LASER	DETECTOR	DATA RATE
1970s	ATS-F (GEO)	Heterodyne	CO2 (gas)	HgCdTe	300 Mbps
1980s	ACTS (GEO)	Direct Detection	Laser diode	APD, PIN	220 Mbps
1990s	ISS (LEO), TDRSS-LIGHT(GEO)	Direct Detection	Laser diode	APD	1.2 Gbps
2000-2005	MLCD (Mars) manage MIT-LL/JPL	Direct Detection	Fiber laser	APD array	50 Mbps
2005-2010	Lab Testbed	Direct Detection	Fiber laser	Hybrid PMT	50 Mbps
2010 - 2015	LLCD (Lunar) Manage MIT-LL	Direct Detetion	Fiber laser	NbN Nanowire	622 Mbps

PROCEEDINGS OF THE IEEE, VOL. 65, NO. 2, FEBRUARY 1977 221

CO_2 Laser Communication Systems for Near-Earth Space Applications

JOHN H. McELROY, SENIOR MEMBER, IEEE, NELSON McAVOY, EDWARD H. JOHNSON, MEMBER, IEEE, JOHN J. DEGNAN, FRANK E. GOODWIN, MEMBER, IEEE, D. MICHAEL HENDERSON, MEMBER, IEEE, THOMAS A. NUSSMEIER, LYLE S. STOKES, BERNARD J. PEYTON, SENIOR MEMBER, IEEE, AND THEODORE FLATTAU, MEMBER, IEEE

EARLY SPECULATION on the applicability of lasers to space co concentrated on deep-space missions (see, e.g., [1]-[4]). In t the 1960's it became evident that the more important E EARL on the applicability of lasers to space communications concer space missions (see, e.g., [1]-[4]). In the latter half of the 19 evident that the more important application was to near-Eart particularly in support of remote sensing applications [5], [6 the technology of terrestrial CO2 laser communication links h the point where the basic parameters were known and a cred could be made for system feasibility [7]-[9]. After an atter communications system on the ATS-F satellite was cancelled budget constraints, a systematic development program was i objective of removing all possible uncertainties before again c resources to a flight experiment. This program was begun in1 results are described here.

Abstract

Proceedings of SPIE -- Volume 2123
Free-Space Laser Communication Technologies VI,

Options for selected articles

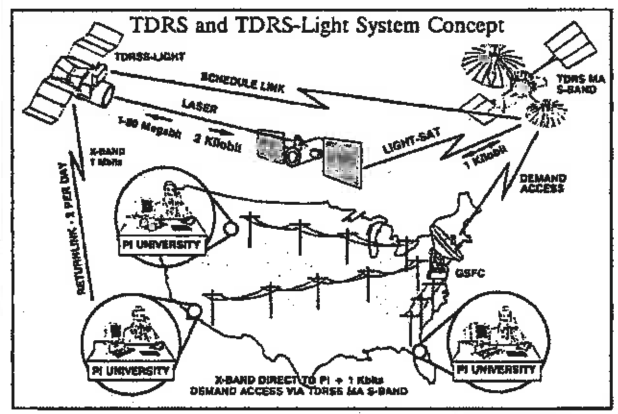
Choose an action Go

Full Text: { PDF (411 kB) }

Tracking and Delay Relay Satellite System (TDRSS)-LIGHT: a space communications architecture

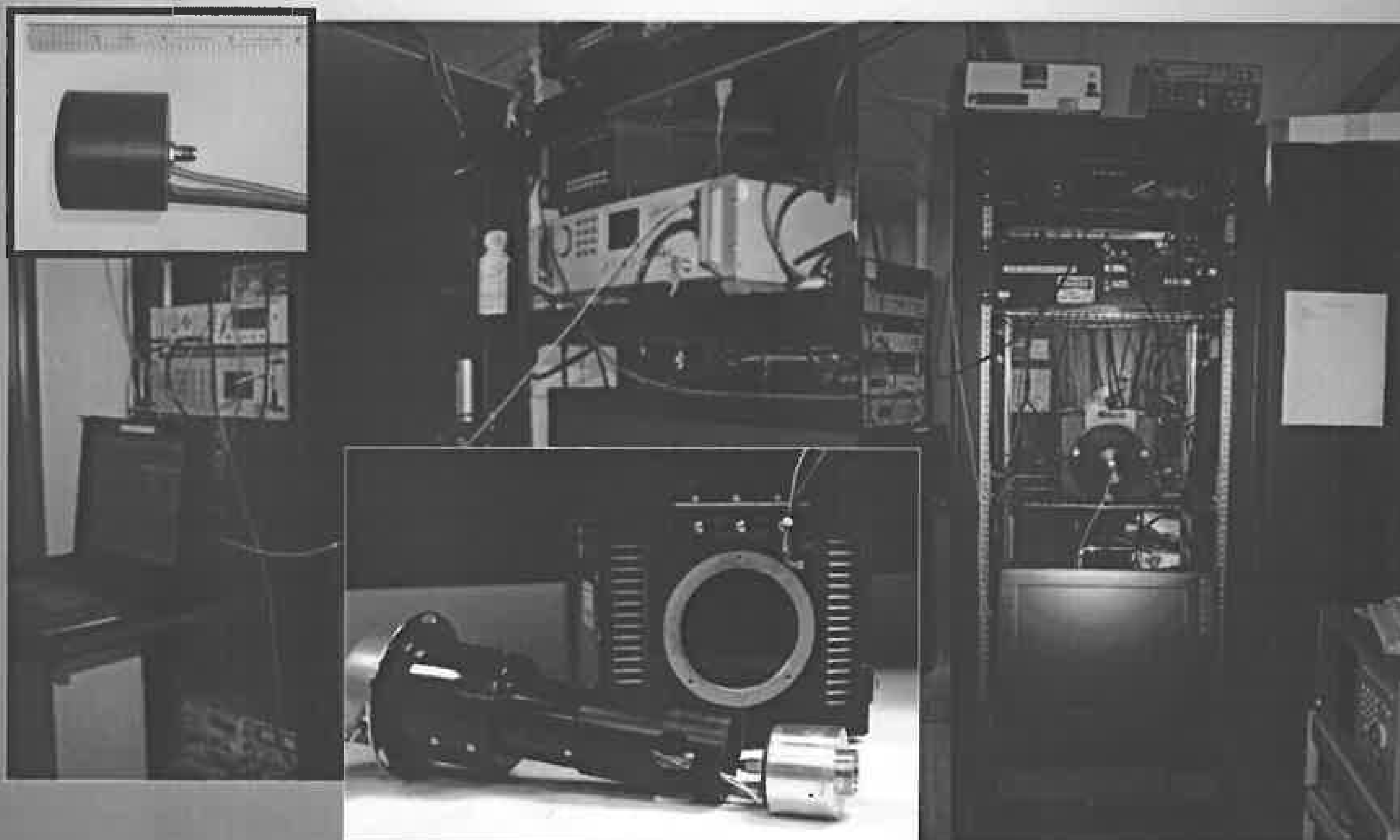
Barnard D. Seery, Michael W. Fitzmaurice, William L. Hayden, Joseph Burt, Peter O. Minott, and Michael A. Krainak
NASA Goddard Space Flight Ctr. (USA)

There is a growing interest in applying the resources of the Tracking and Data Relay Satellite System (TDRSS) as the primary support capability for future small satellite users. This interest is based on a variety of benefits offered by the TDRSS, and not available with globally-distributed space-ground links. An architecture based on an optical augmentation to the current TDRSS space network is discussed, including a candidate design for the user and relay terminals.



Goddard Space Flight Center JPL Space Systems Loral

PPM Laser Communication Transceiver Testbed Demonstrated Photon counting at 1um



Ref: 2008, SPIE 6877-2, Krainak

Laser Communications Greenbelt, MD to Lunar Reconnaissance Orbiter Uplink

- First successful test, 5/9/2011, 3:40 pm EDT

Free space laser communication experiments were conducted between the satellite laser ranging (SLR) station at NASA Goddard Space Flight Center and the Laser Ranging (LR) receiver on the Lunar Reconnaissance (LRO) over a 380,000-km distance in May 2011. The laser pulse trigger times were modulated by a 1024-ary pulse position modulation (PPM) signal centered in the LR range gate interval. The received signal showed an 80% PPM word detection rate, which was typical for laser ranging measurements through atmosphere under a clear sky condition.

Ref: X.Sun, 8246-16 of SPIE 2012 Photonics West Conference

Heritage Elements – Mars Laser Communication Demonstration

Mars Terminal

- Generate Optical Power
- Encode and Modulate the Data between .1 and 50 Mbps
- Point and stabilize outgoing beam through a Hybrid inertial / beacon concept.
- Receive uplink commands at approximately 10 bps

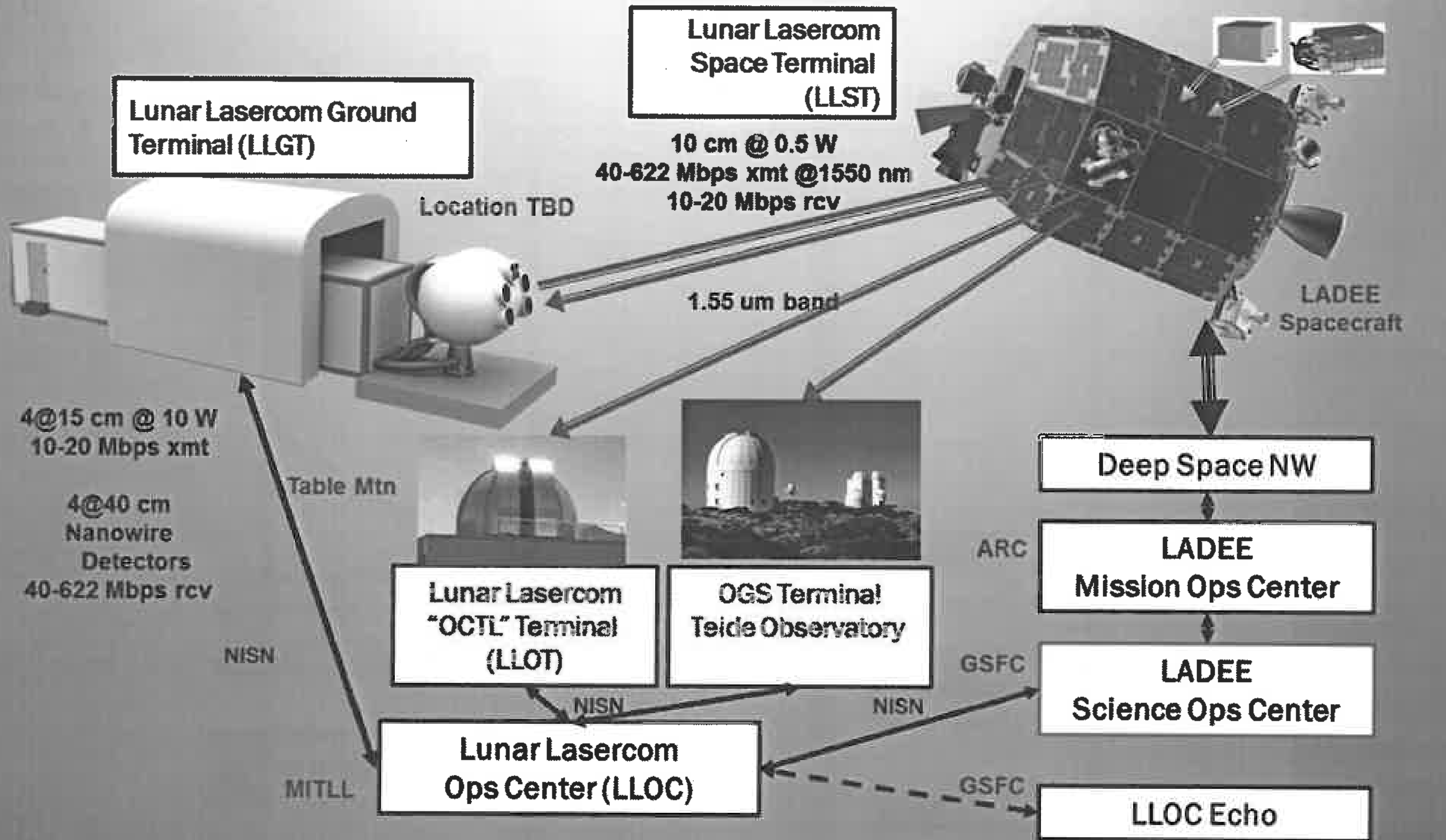
Earth Terminal

- Considered Ground-based, Balloon-based, and Space-based terminals.
- A large aperture area is needed to collect enough light to overcome the extreme range.
- Need to couple capture light onto efficient detection hardware.
- Demodulate and decode the signal.
- Transmit a beacon and uplink commands.
- Needs to operate in daylight

Link Control

- Dynamically select terrestrial site and inform Mars terminal
- Optimize lasercom parameters for changing conditions and inform all terminals
- Coordinate transmission, buffers, retransmissions, ...

Heritage Elements – Lunar Laser Communication Demonstration



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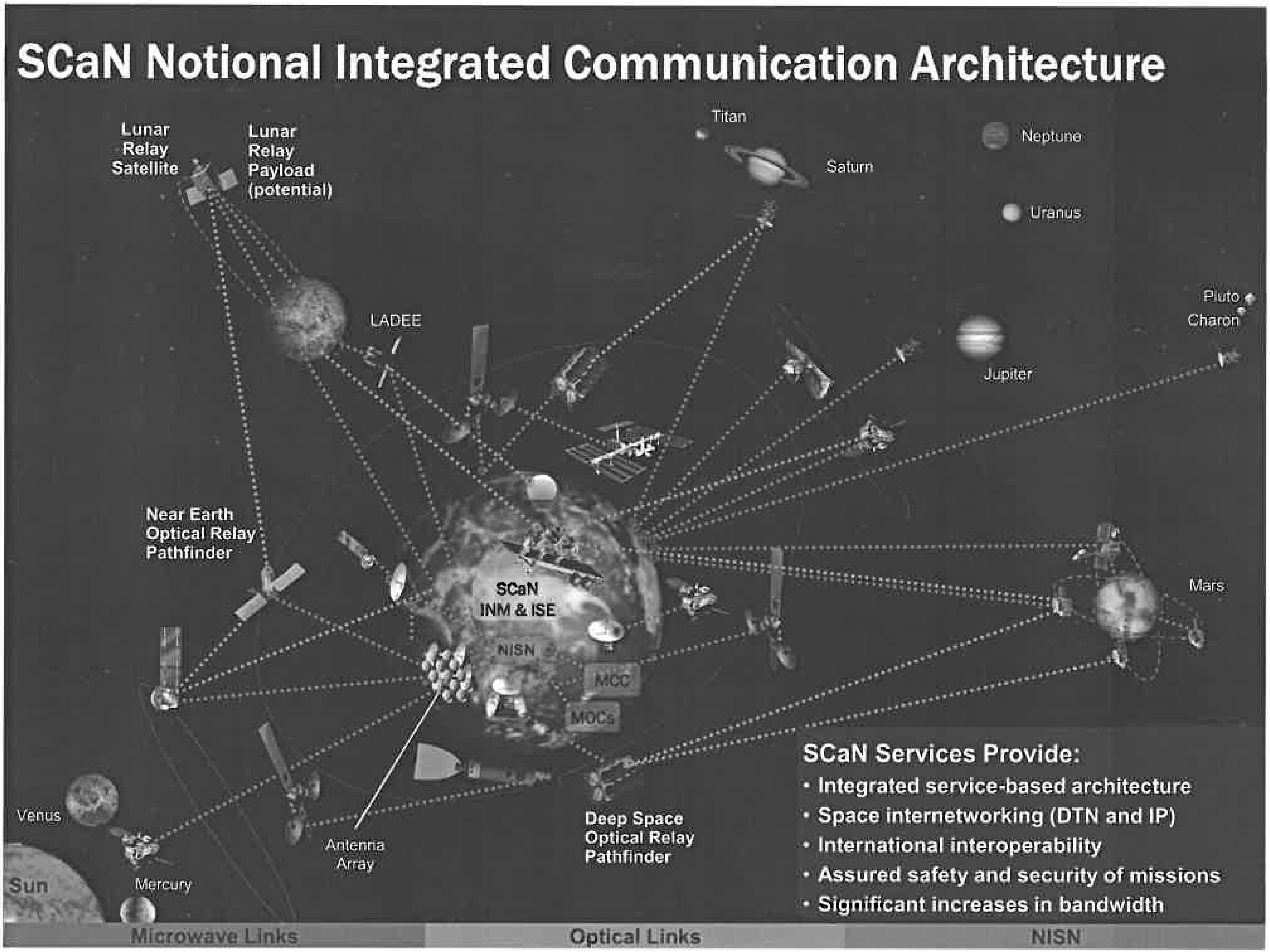
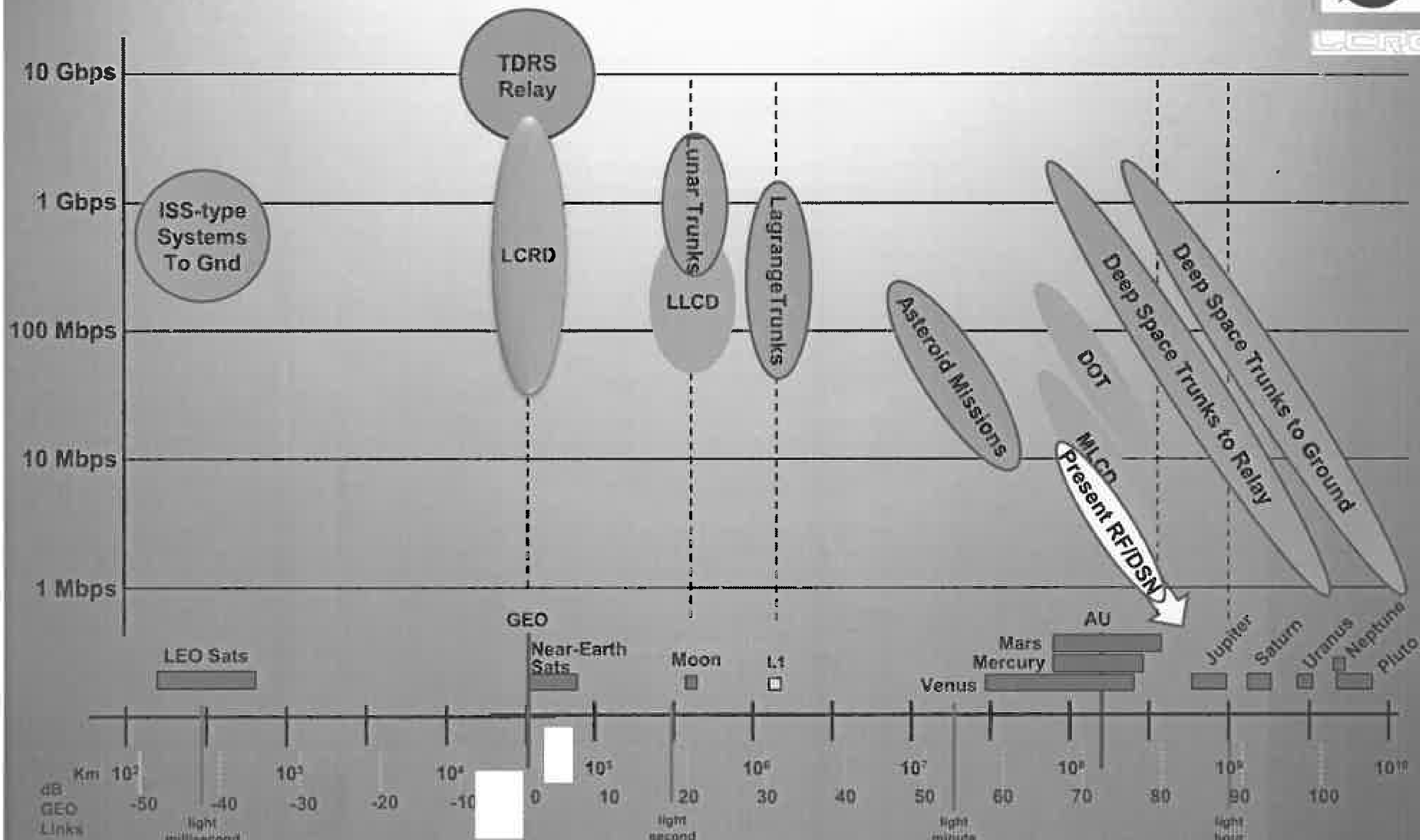

SCaN Notional Integrated Communication Architecture
Lunar Relay Satellite
Lunar Relay Payload (potential)
Titan
Neptune
Saturn
Uranus
LADEE
Pluto
Charon
Jupiter
Near Earth Optical Relay Pathfinder
SCaN INM & ISE
NISN
MCC
MOCs
Mars
Venus
Antenna Array
Deep Space Optical Relay Pathfinder
Sun
Mercury
SCaN Services Provide:
• Integrated service-based architecture
• Space internetworking (DTN and IP)
• International interoperability
• Assured safety and security of missions
• Significant increases in bandwidth
Microwave Links
Optical Links
NISN

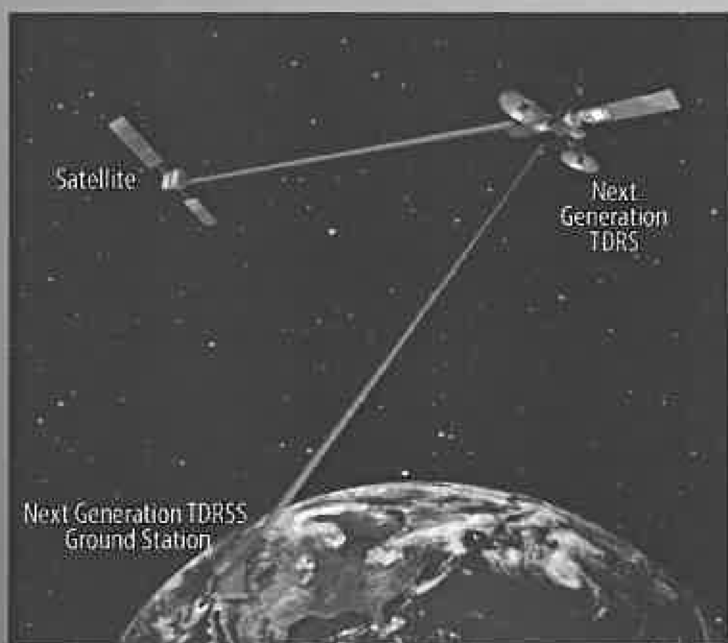
Some NASA Goals



Goddard Space Flight Center JPL Space Systems Loral

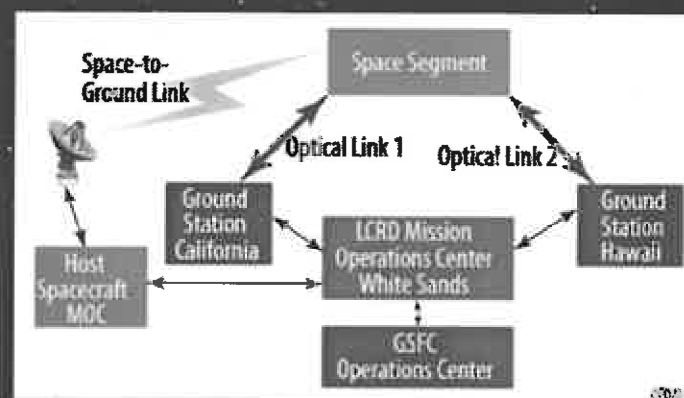
LCRD Mission Statement

LCRD will demonstrate optical communications relay services between geosynchronous orbit (GEO) and Earth over an extended period, and thereby gain the knowledge and experience base that will enable NASA to design, procure, and operate cost-effective future optical communications systems and relay networks

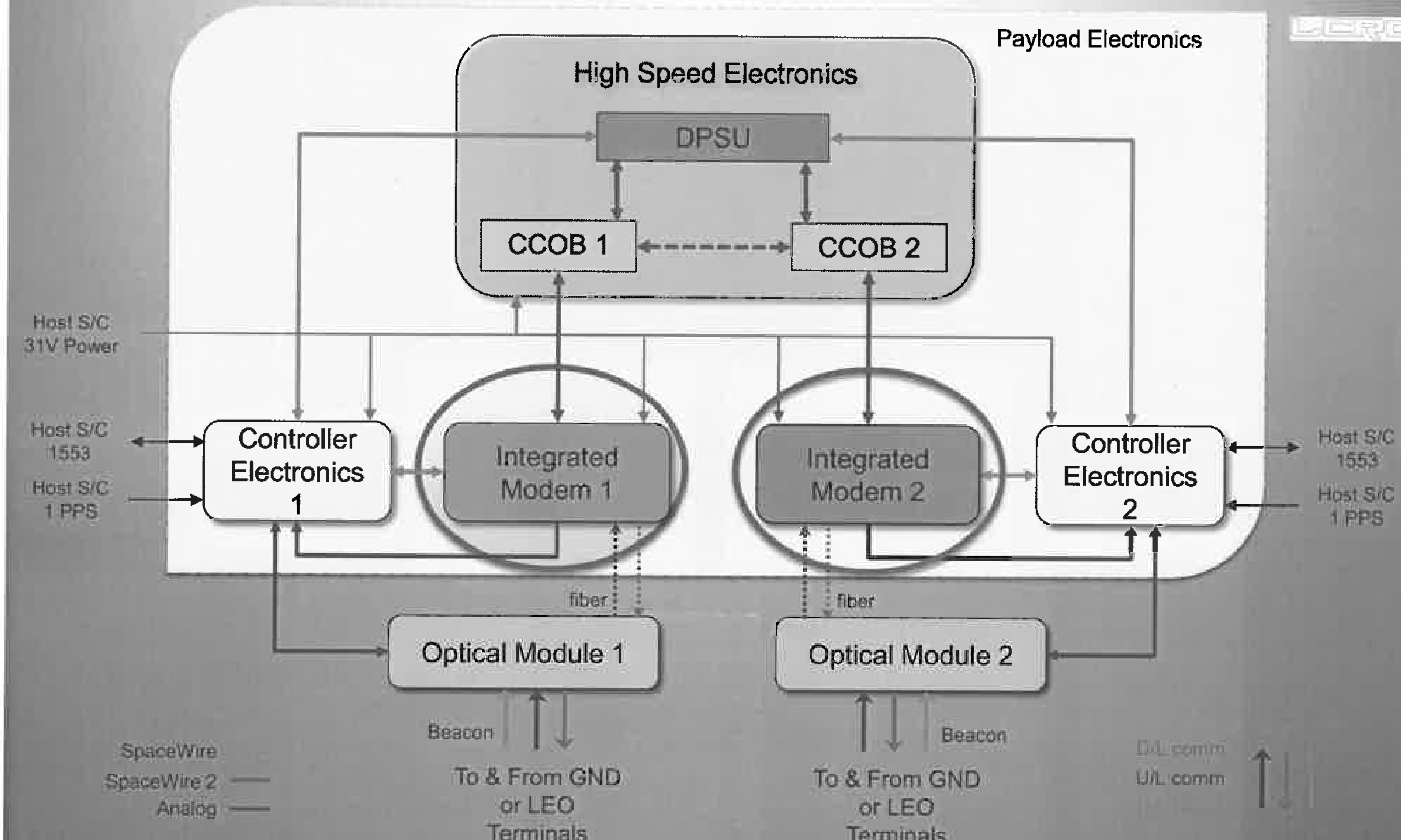


LCRD Mission Architecture

- Commercial Spacecraft Host
- Flight Payload
  - Two Lunar Laser Communication Demonstration (LLCD) based Optical Modules
  - Two LLCD Pulse Position Modulation Modems
  - Two Multi-Rate Differential Phase Shift Keying Modems based on a MIT Lincoln Laboratory Design
  - Two Optical Module Controllers
  - High Speed Electronics to interconnect the two terminals, perform data processing, and to interface with the host spacecraft
- Two Optical Communications Ground Stations
  - Upgraded JPL Optical Communications Telescope Laboratory (Table Mountain, CA)
  - Upgraded LLCD Lunar Laser Ground Terminal (Location TBD)
- LCRD Mission Operations Center
  - Connected to the two LCRD Optical Communications Ground Stations
  - Connected to the Host Spacecraft Mission Operations Center



LCRD Payload Electronics Architecture



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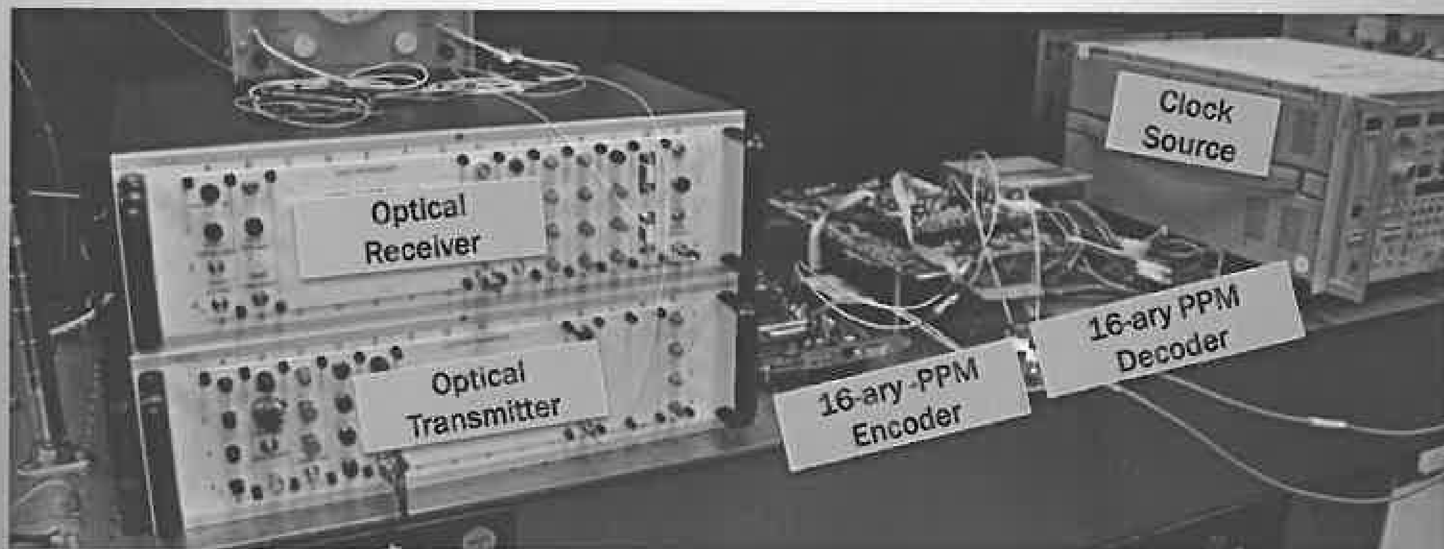
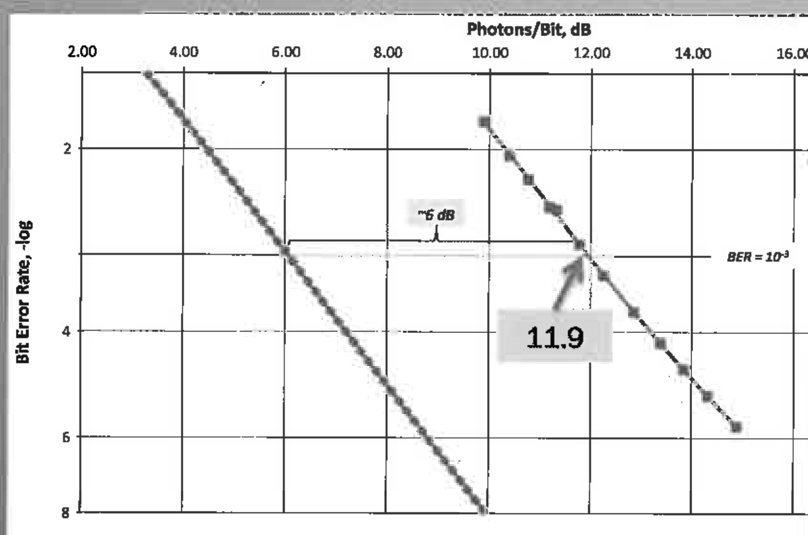
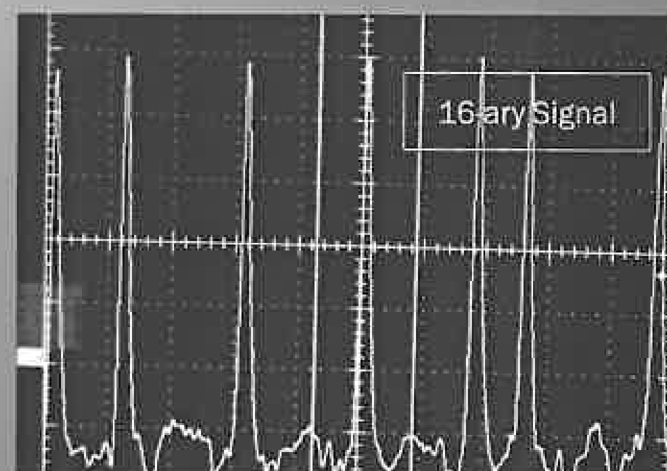
PPM Modem Testbed
16-ary PPM at 5 GHz slot rate was successfully demonstrated

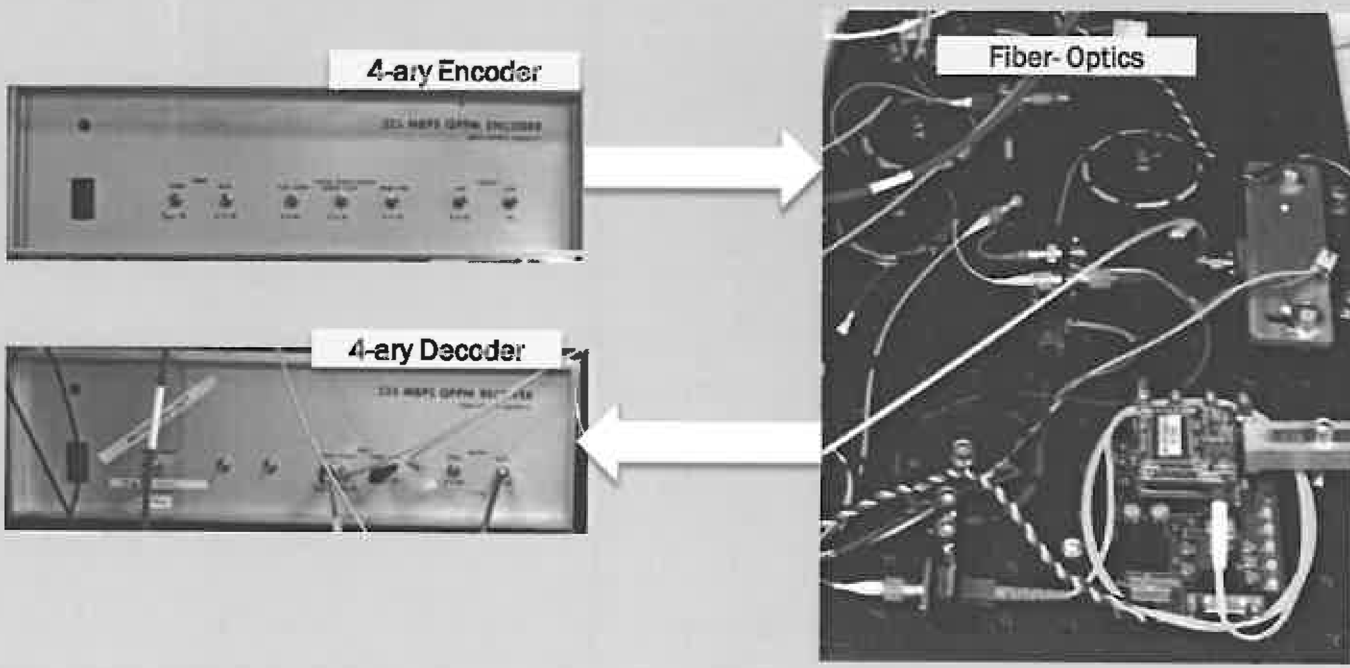






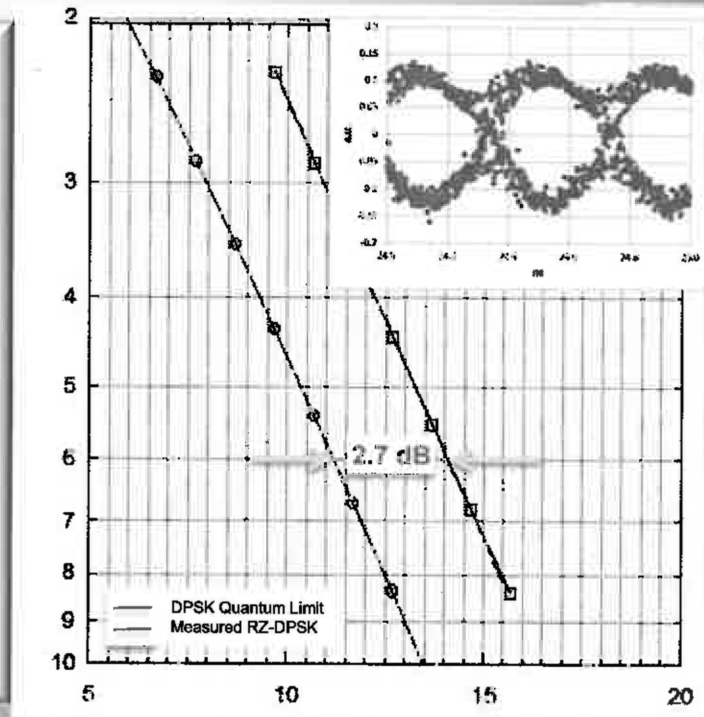
PPM Modem Testbed:
Demonstrated Functionality of 4-ary PPM (LLCD Uplink)

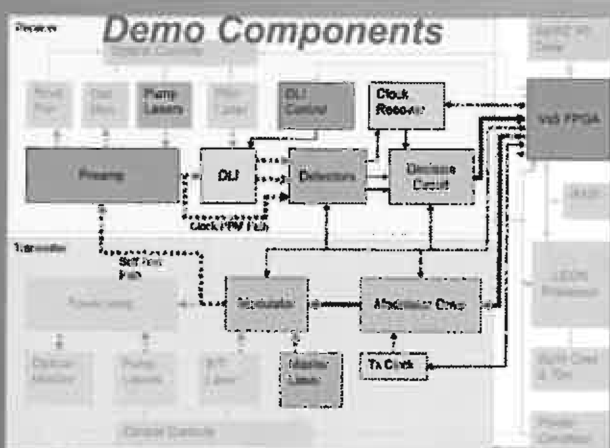
- 4-ary PPM (uplink)
  - 325 Mbps slot rate encoding and decoding
  - Automated Modulator Bias control for high Extinction Ratio
  - Built with heritage Encoder and Decoder

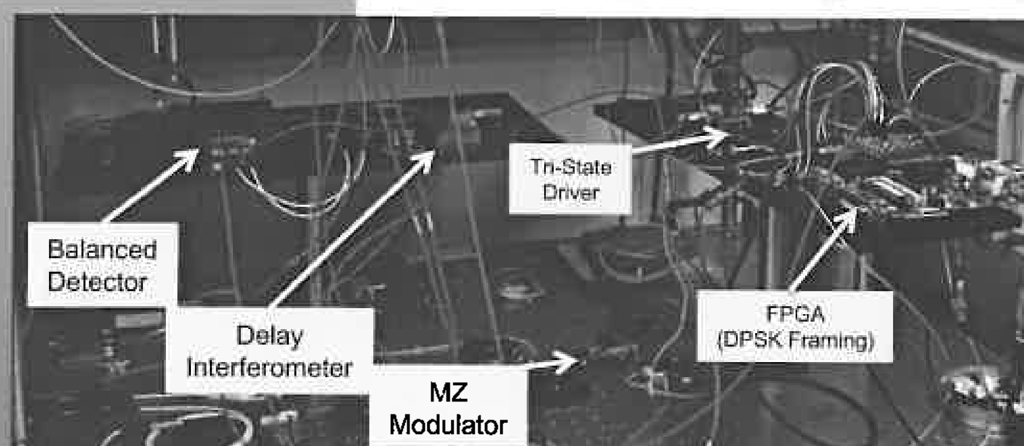


DPSK Modem Breadboard Demonstrated LCRD Required Performance

- RZ-DPSK breadboard with tri-state driver was successfully assembled, tested and demonstrated
  - Assembled out of COTS components
  - Performance verified to be within 2.7 dB from the quantum limit
- FPGA loaded with DPSK image to generate objective framing
  - Xilinx Virtex-6
  - tri-state generation
- Achieved 1e-6 BER with 25 photons per bit
  - Optimizing signal integrity from FPGA will improve performance
  - FPGA clocking scheme improvement will reduce jitter penalty







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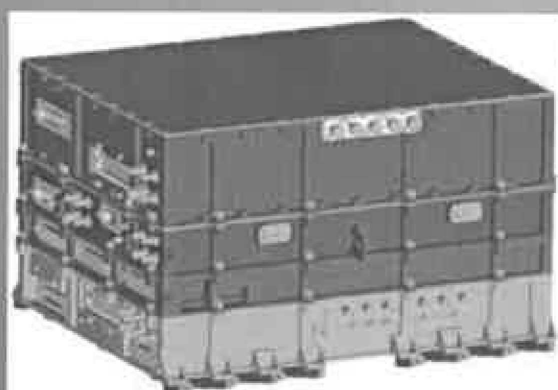
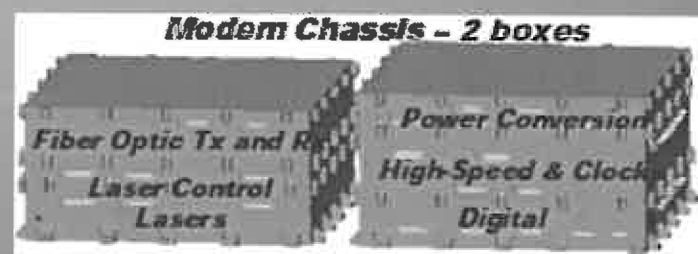
Challenges of combining modems

- Different clocks (only optics can be shared)
- Inherited different data frame structure
- The same wavelength
- Polarization diverse receivers


PPM Modem

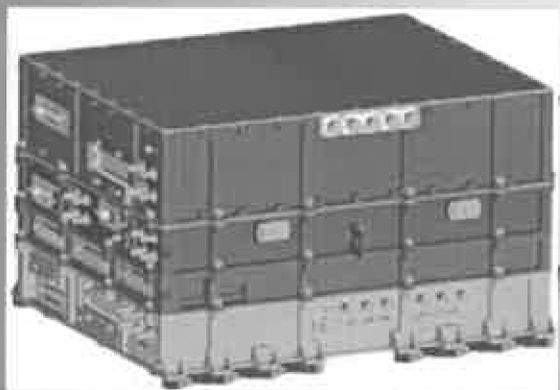


DPSK Modem

PPM and DPSK Modems Combining options

Assumptions	Solutions		Impact
Case 1: No changes to the existing MITLL modems designs	Combine/ split optical signals between modems and Optical Module	Power	• dBs of additional link loss each way for both modulations • Additional component
		WDM	• sub-dB of additional link loss each way for both modulations • Tune/replace wavelength selecting components on PPM modem • Additional wavelength selecting component
		Polarization	• sub-dB of additional link loss each way for both modulations • Additional polarization controlling component • Additional polarization selecting component
		Switching	• sub-dB of additional link loss each way for both modulations • Additional switching component (requires electrical connectivity for control)
Case 2: Minor Functional Changes to the modems designs not impacting performance.	Combine/ split optical signals inside one of the modems; HPA and LNA of one of the modems are shared	Power	• Two fiber connections between PPM and DPSK modems • Additional component
		WDM	• Two fiber connections between PPM and DPSK modems • Tune/replace wavelength selecting components on PPM modem • Additional wavelength selecting component
		Polarization	• Two fiber connections between PPM and DPSK modems • Additional polarization controlling component • Additional polarization selecting component
		Switching	• Two fiber connections between PPM and DPSK modems • Additional switching component (requires electrical connectivity for control)
Case 3: Minor modifications to DPSK modem – capabilities not changed. PPM modem can be completely "overhauled"	DPSK Modem upgraded to modulate and detect PPM signals. Clock Recovery detector is used to detect PPM data signals		• Additional component on receive side to split the signal into two optical paths – one for DPSK and the other for clock recovery and PPM threshold detection

Case 1: No changes allowed to be made to existing modems designs



PPM Modem

Options

- Power Combiner
- WDM Multiplexer
- Polarization Combiner
- Power Switch

Controller Electronics

Required for Power Switch only

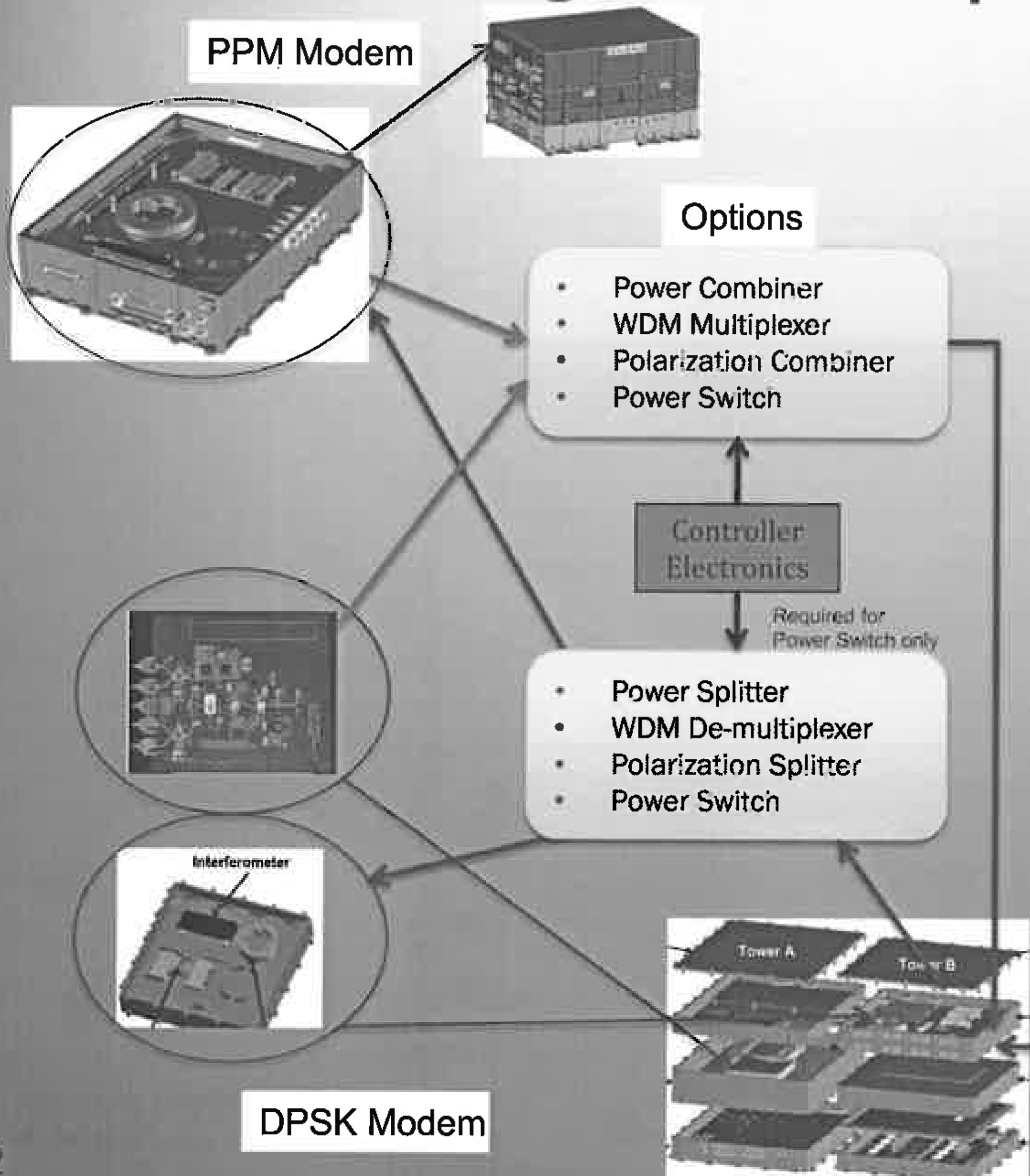
- Power Splitter
- WDM De-multiplexer

Optical Module

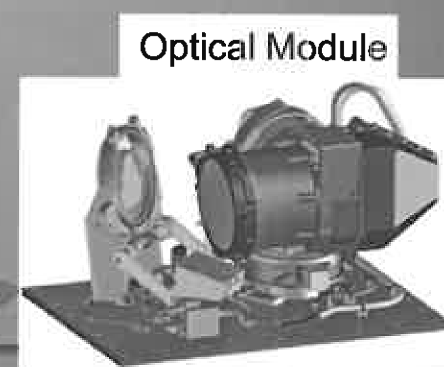
DPSK Modem

Options	Pros	Cons	rating
Power	Simplicity and low SWAP	Largest impact on Link budget	2
Wavelength	Lowest impact on link budget, low SWAP	Required a separate wavelengths for PPM modem TX and RX: same design, different part numbers spectral filtering components	1
Polarization	Low SWAP	The most complex: requires polarization controller on PPM transmitter; may not be feasible for receiver	4
Switch	Low insertion loss	Reliability, needs electrical connection and command to switch	3

Case 2: Minor changes allowed. No performance impact

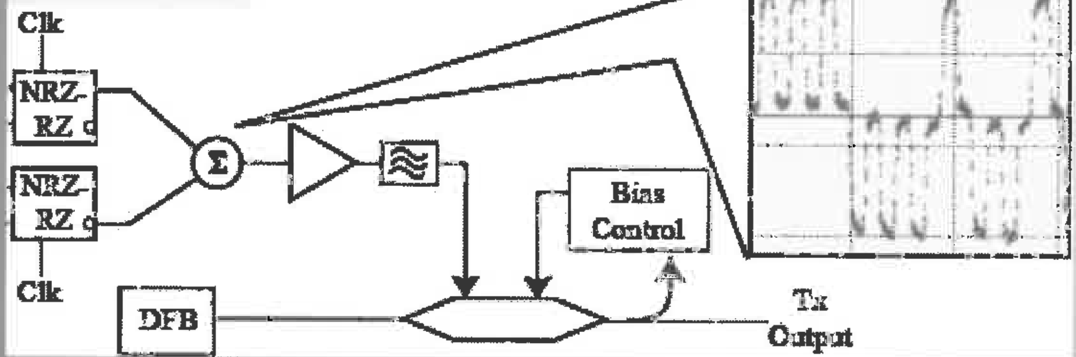


- Selected transmit signal (PPM or DPSK) is amplified by DPSK booster amplifier before reaching Optical Module
- Received signal from Optical module is first amplified by the DPSK 1st stage amplifier, than routed to corresponding (PPM or DPSK) EO slice



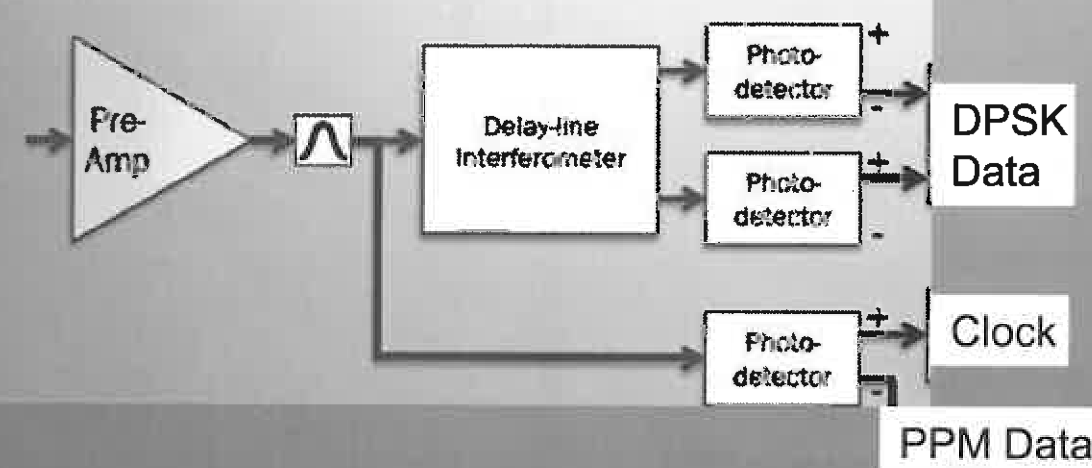
Case 3: Minor Mods to DPSK. PPM can be "overhauled"

Transmitter



DPSK modem is used to generate PPM signals as well

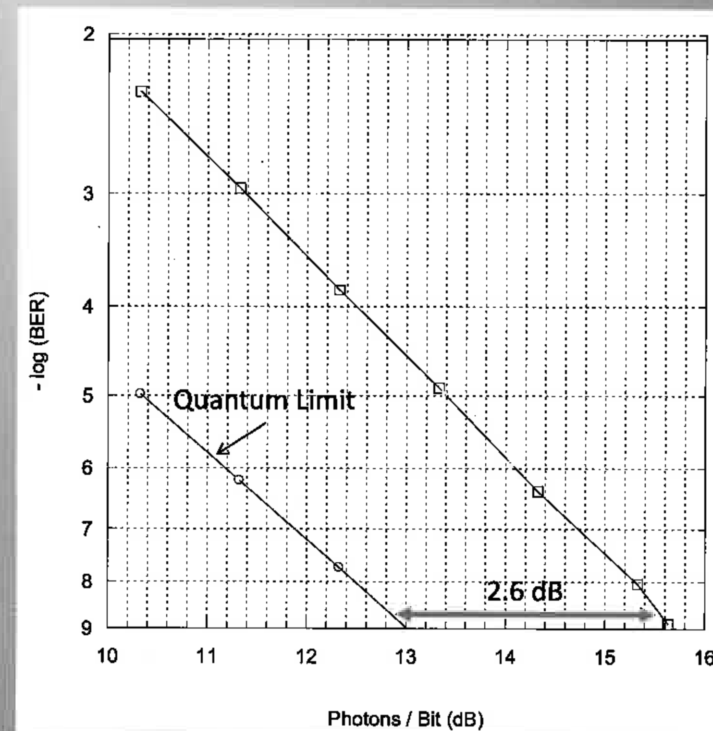
Receiver



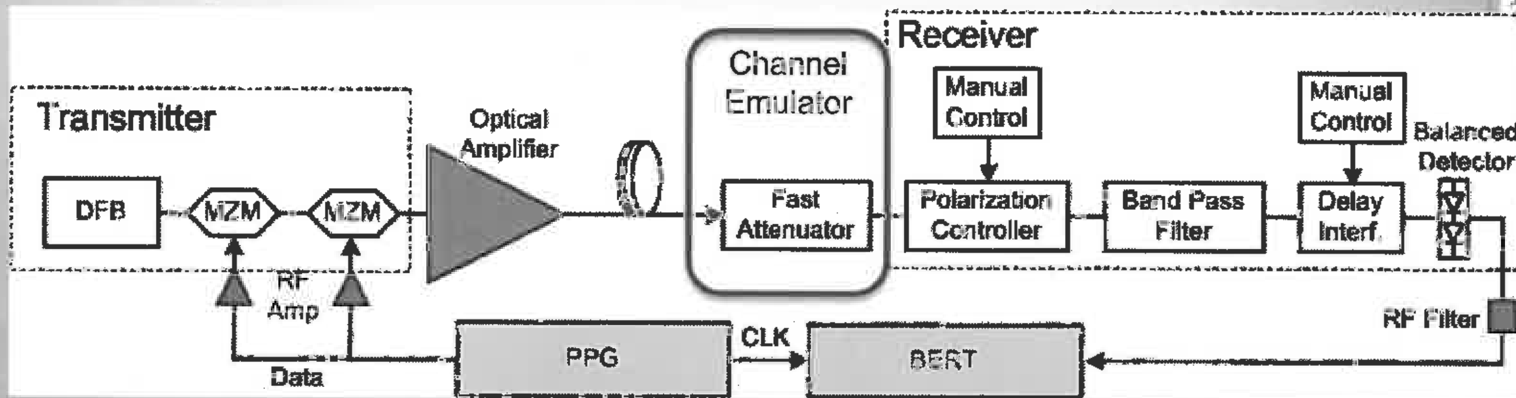
- Transmitter – same tri-state pulse generation for PPM as for DPSK
- Receiver – photo-detector being used for clock recovery is used for PPM detection

Integrated Modem Demonstration

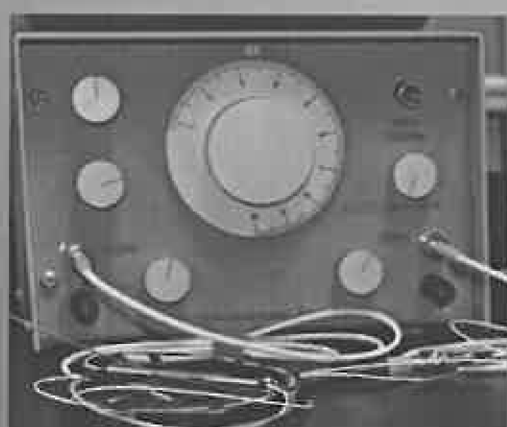
- Used Arbitrary Waveform Generator to create tri-state DPSK and PPM 2.88 Gslots/sec signals
- BERT system used to detect and verify performance of the link – within 2.6 dB from the DPSK quantum limit

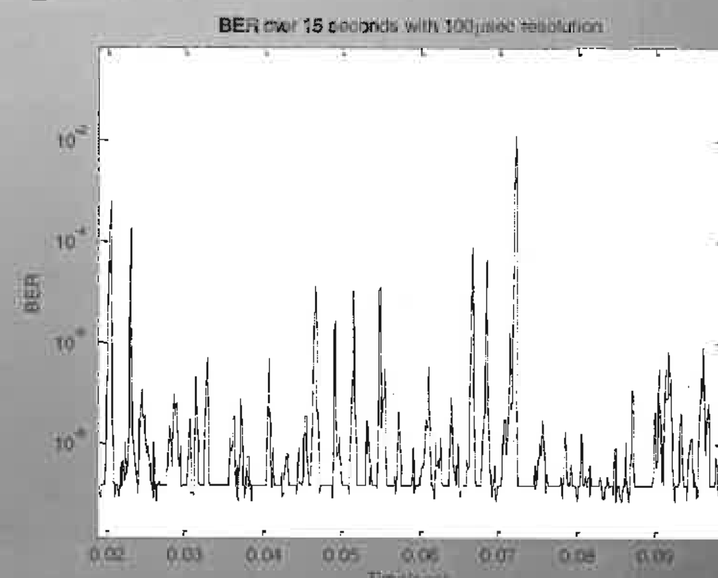


Other Developments Channel Emulator



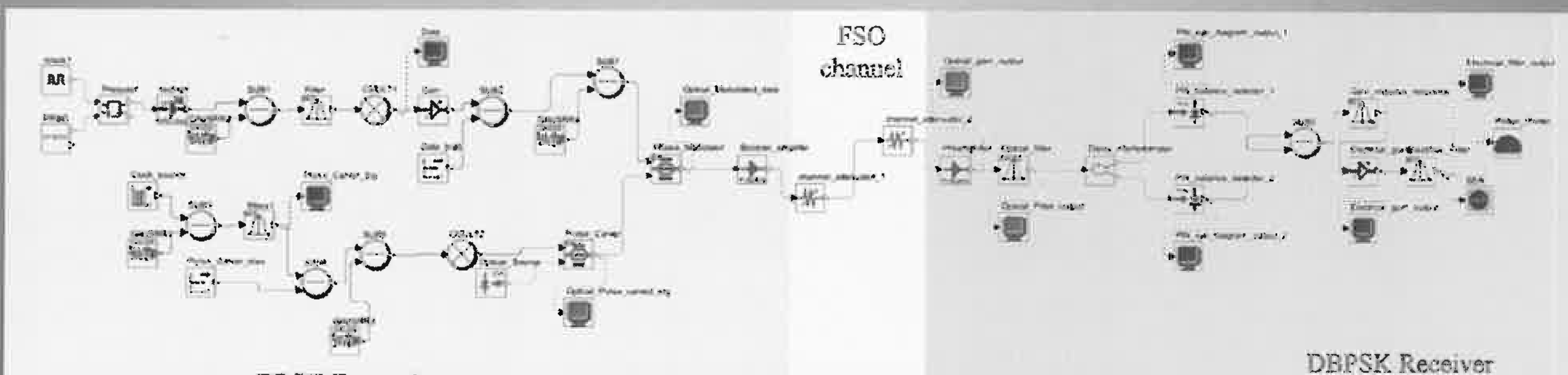
- Simulation of the optical link (channel) is necessary to stress optical modems during test and verification
- Time series Atmospheric model with captured light into fiber
- Calculated BER evolution over time to inject into network modeling tool





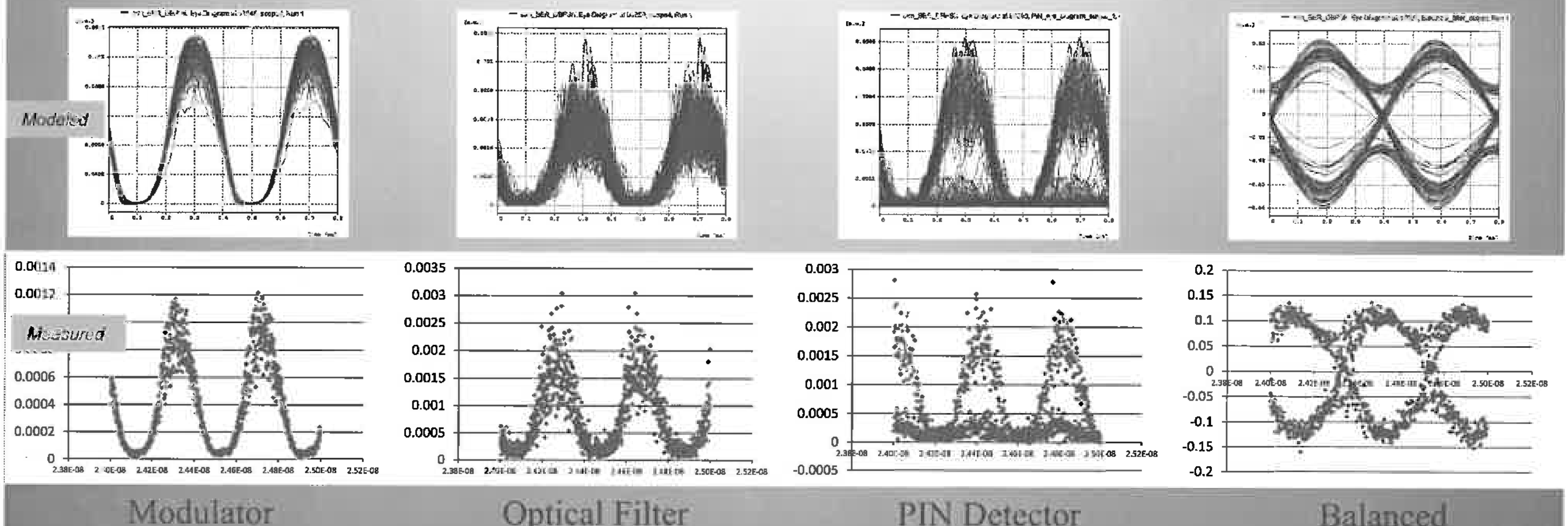
Other Developments – Optical Link Modeling

- Developed a modeling tool to support selection of optimum components and provide system tuning optimization
- Modeled Return-to-Zero DPSK link with COTS software (Optsim, Rsoft)
- Real parameters from actual components were used to model Optsim Components
- Model was verified by matching model and testbed transceiver BER performance



OptSim model for RZ-DBPSK transmitter

Eye Diagrams used to verify Modeling Accuracy

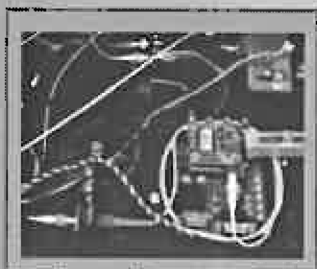


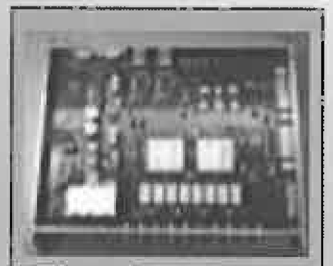
Summary

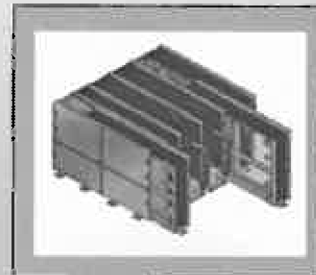
- Successfully built and demonstrated EO elements of PPM and DPSK breadboards operating at required detection sensitivities
- Demonstrated Combined Modem operation
- Built and tested Atmospheric Channel Emulator
- Developed realistic LCRD optical communication modeling tool
- Challenges include identification and qualification of appropriate replacements for obsolete components in original designs

Path Forward

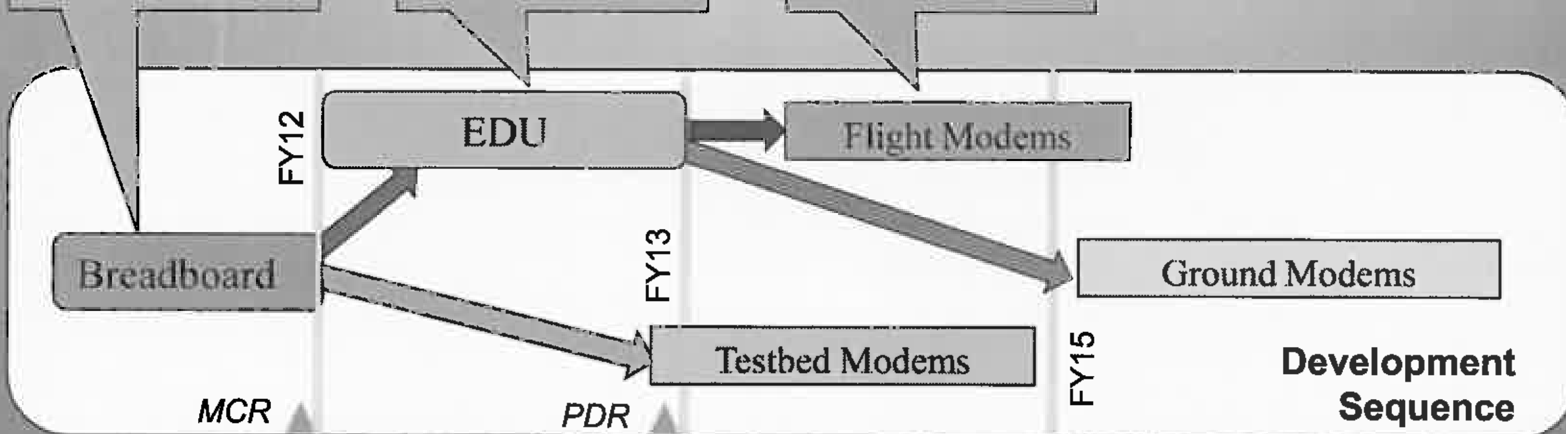
- (Near Term) Development of the Engineering Development Units
  - Serve as performance qualification modems for the flight terminals
  - Lately will be updated to constitute modems for the ground stations







- EDU 9/2013 (3 units)
- FLT 8/2014 (2 units)
- Update EDUs for GRD 9/2016 (2 units)

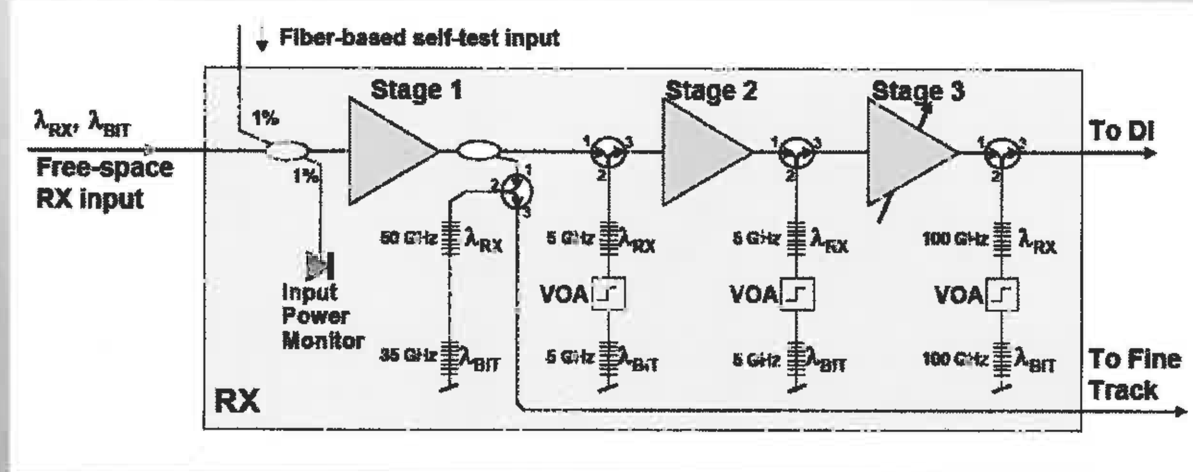


- Qualification of replacements for obsolete components

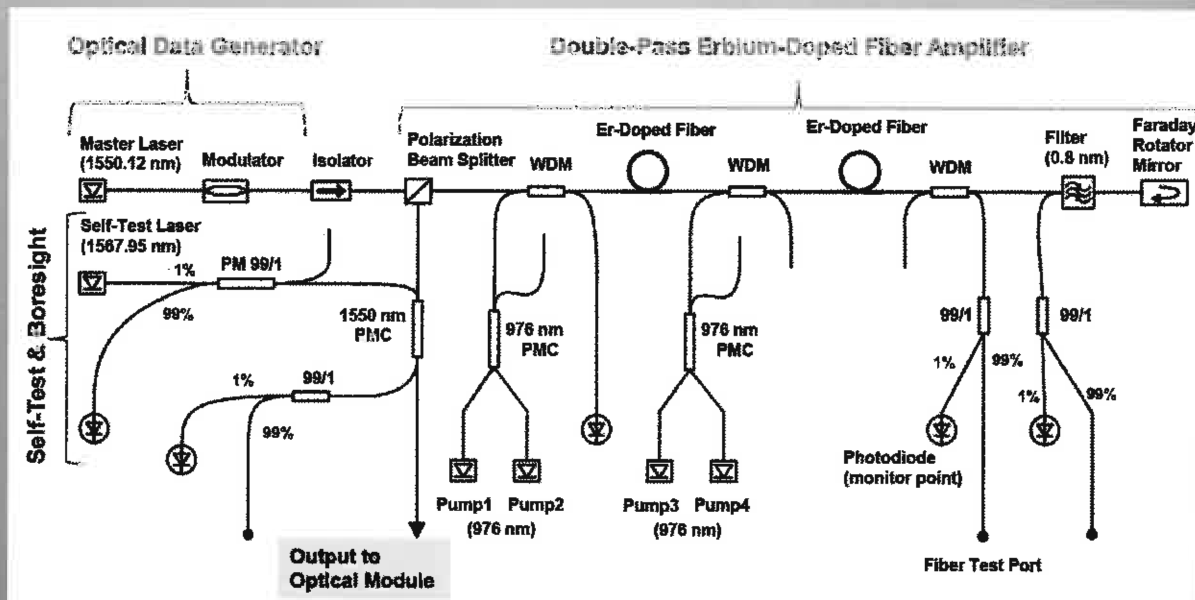
Back-up

Erbium Doped Fiber Amplifiers

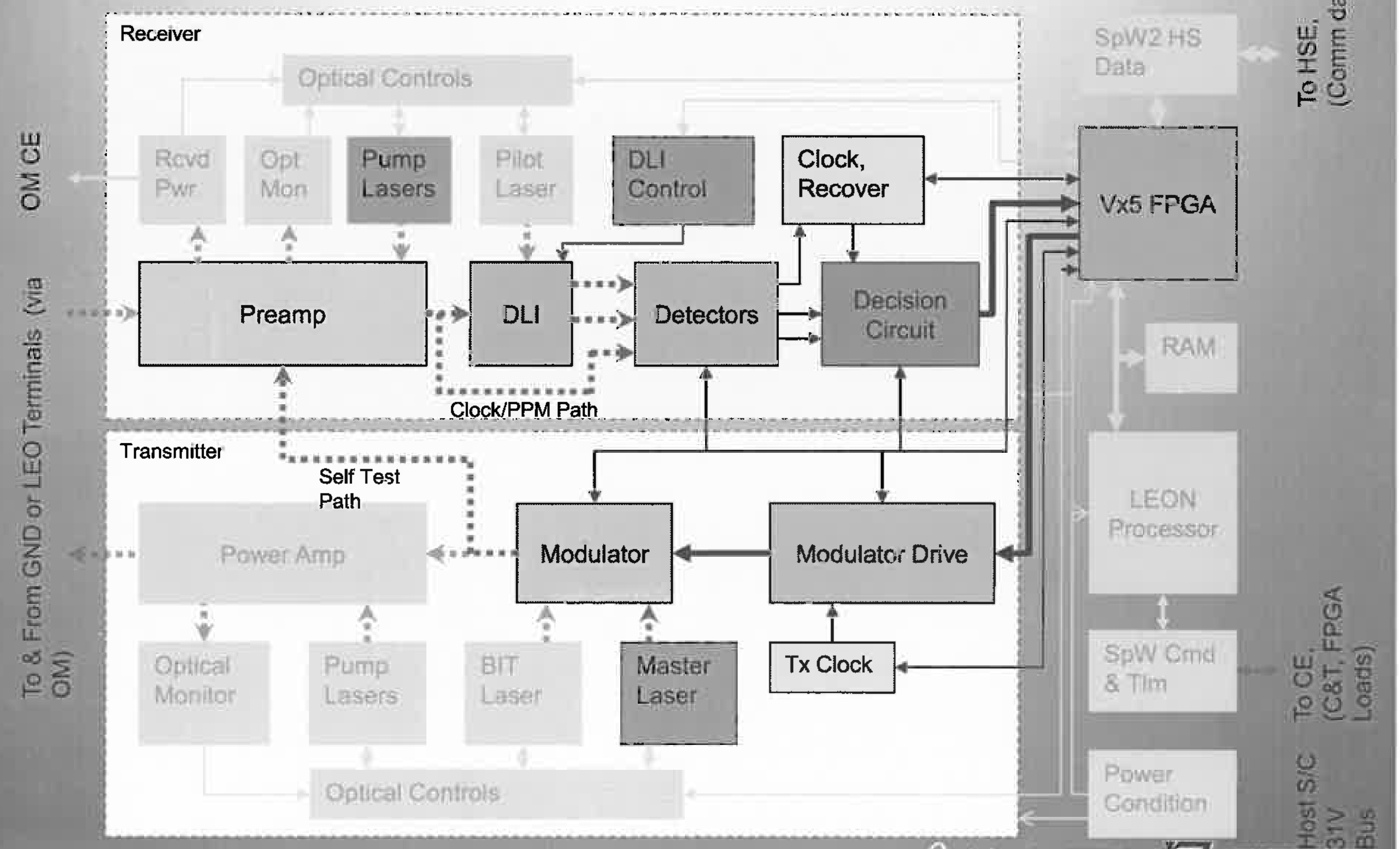
- RX Low Noise Amplifier



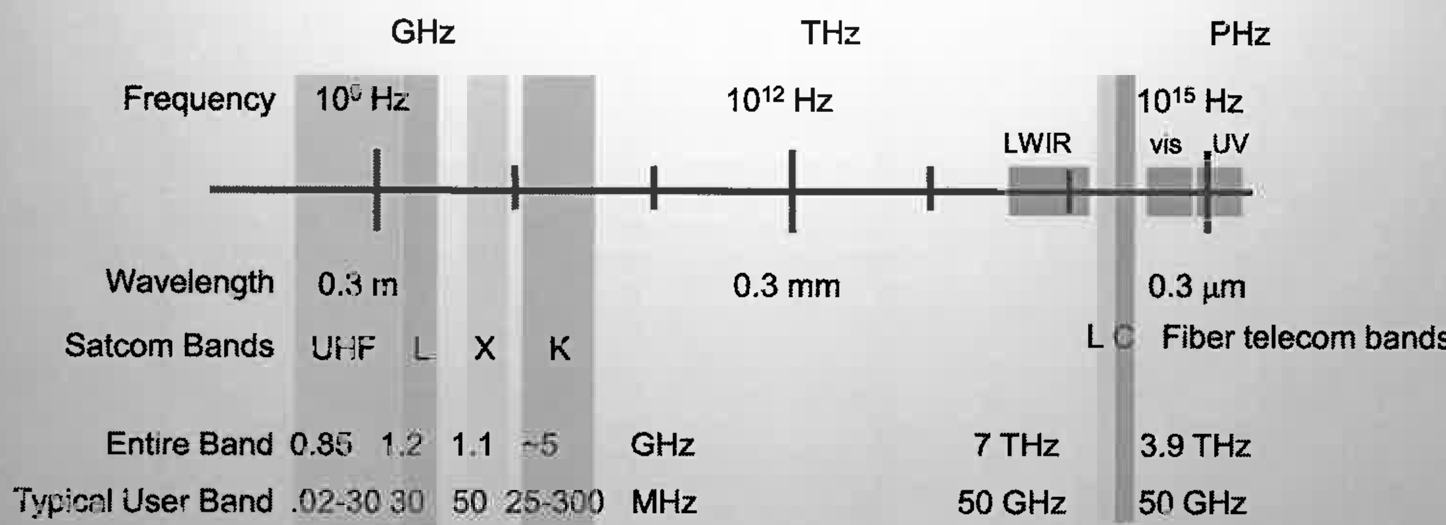
- TX Booster Amplifier



LCRD Integrated Modem



Laser Communications Potential



Features of extremely short wavelengths of IR light	System Potential	Improvement Over RF
Nearly infinite bandwidth (and fiber telecom components to make use of it)	- ***Extremely high data rates*** in ***unregulated bands*** - Use of extra bandwidth to achieve very high efficiency	10's of THz vs 50 GHz
Extremely high gain from small apertures	***Very small terminals***	Power delivery efficiency $10{,}000^2$ greater

The Power of Wavelength!

RF

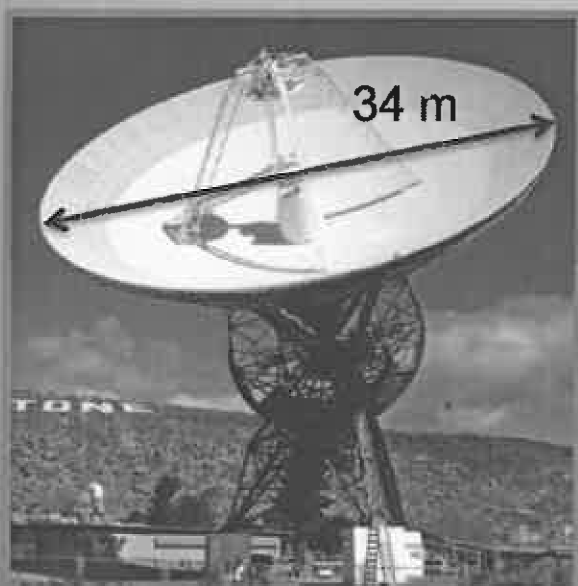
- 34-m antenna
- S-band (~2-2.3 GHz)
- 20-kW transmit power

Optical

- 10-cm space terminal
- Optical (192 THz !!!)
- 0.5-W transmit power

Equivalent Isotropic Radiated Power Comparison

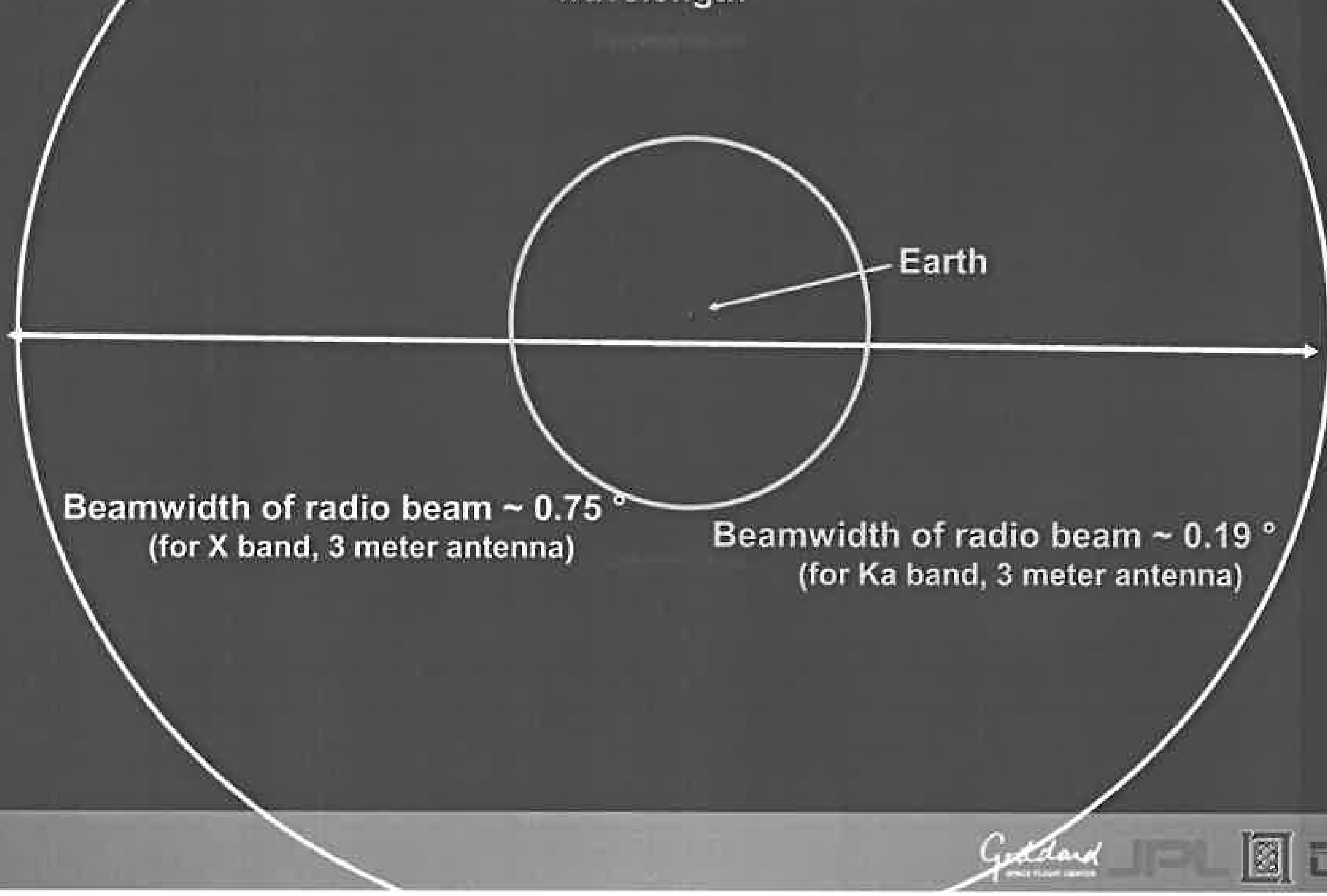
→ EIRP = 8.3 GW



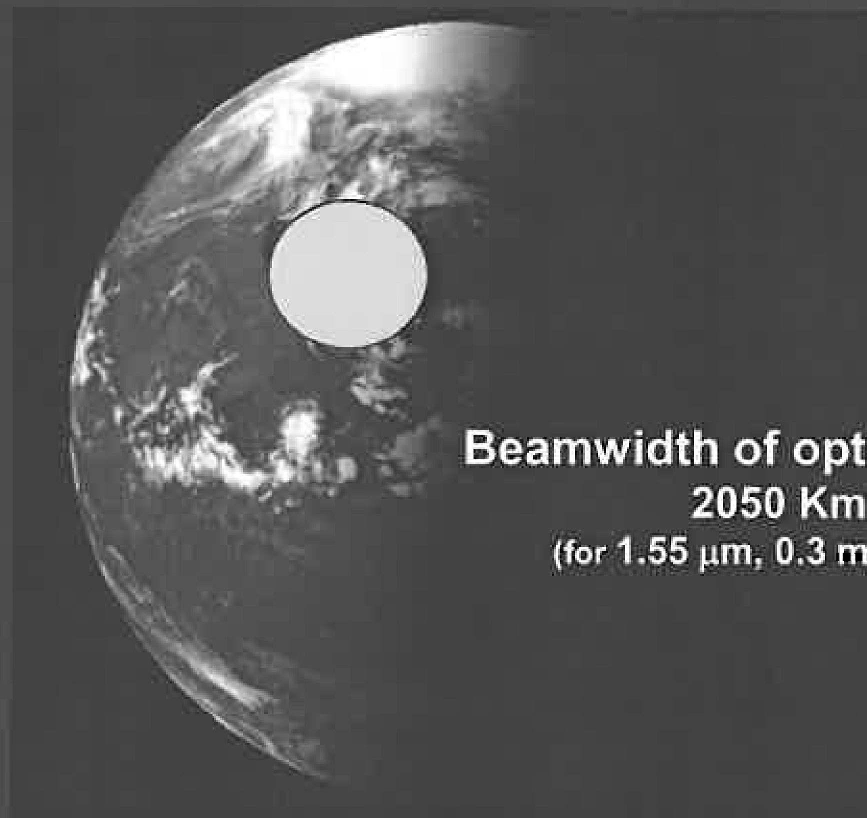
→ EIRP = 8.1 GW

Beamwidth Example: Radio from Mars

When an antenna (or telescope) is optimally focused, its beam still diverges at an angle proportional to the wavelength



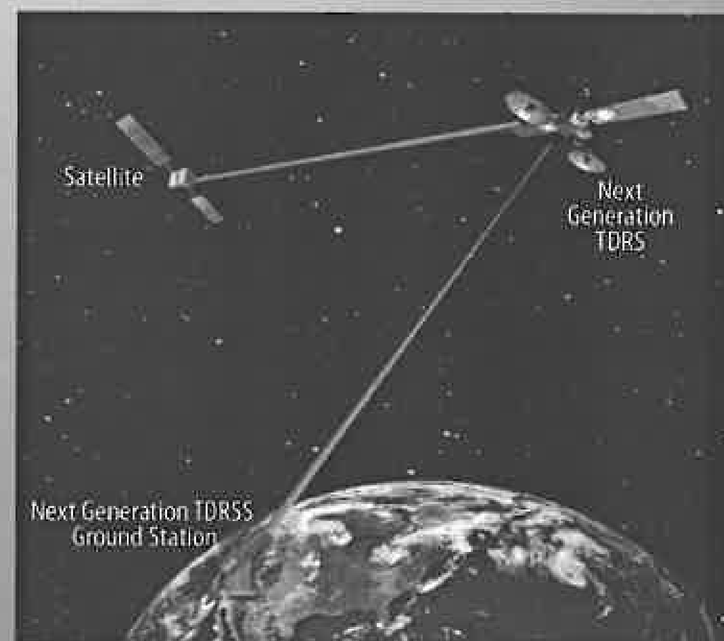
Beamwidth Example: Optical from Mars



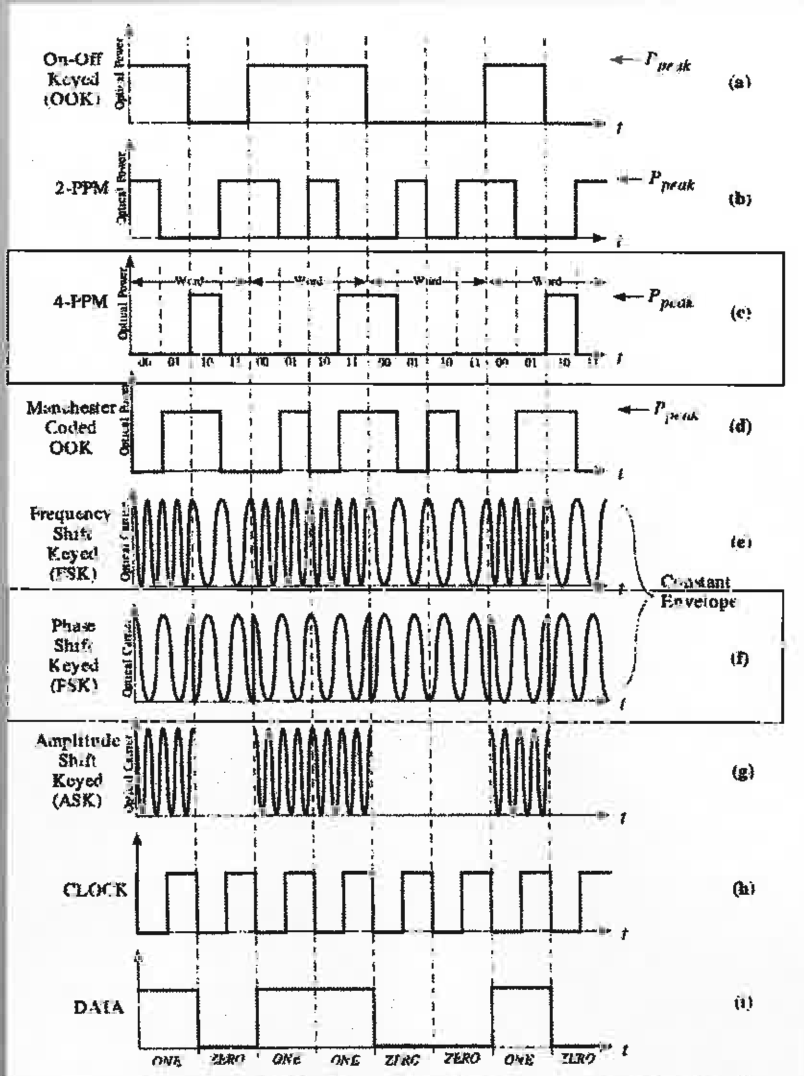
Beamwidth of optical beam ~ 0.00029 °
2050 Km
(for 1.55 μm, 0.3 meter)

LCRD Demonstration Scenarios

- LCRD will operate in multiple configurations to support a variety of scenarios
  - Optical link and hardware characterization
  - Direct-to-Earth Operations
  - Relay Operations



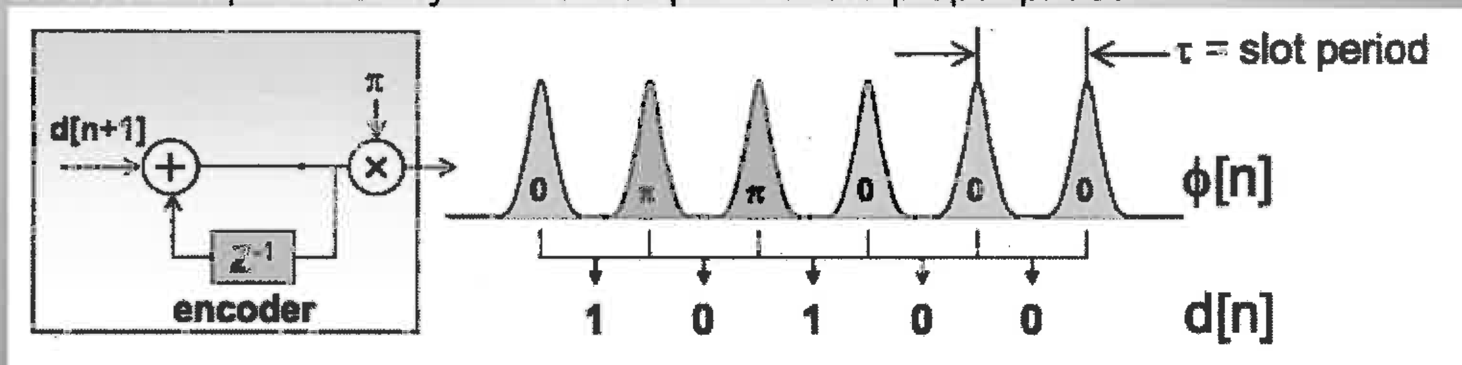
Modulation Techniques



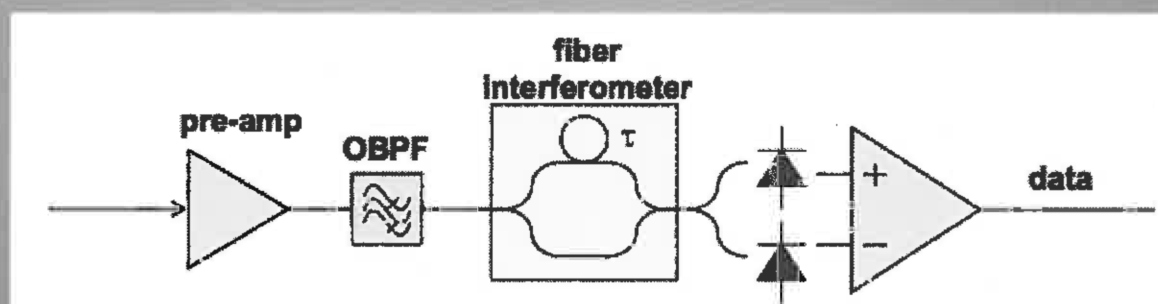
Modulation Format	*Receiver Structure*	*BER Expression*	*Sensitivity Peak Photons per bit n_p*	*Sensitivity Average Photons per bit*
PSK	Quantum Optimum	$\approx \frac{1}{2}e^{-4n_p}$	5	5
PSK	Homodyne	$= Q\left(\sqrt{4n_p}\right)$	9	9
PSK	Heterodyne Synchronous	$= Q\left(\sqrt{2n_p}\right)$	18	18
OOK	Photon Counting	$= ?^{-n_p}$	20	10
DPSK	Heterodyne	$= \frac{1}{2}e^{-n_p}$	20	20
DPSK	Preamplified Direct detection	$= \frac{1}{2}e^{-n_p}$	20	20
ASK (OOK)	Homodyne	$= Q\left(\sqrt{n_p}\right)$	36	18
FSK	Heterodyne Synchronous	$= Q\left(\sqrt{n_p}\right)$	36	36
FSK	Heterodyne Asynchronous	$= \frac{1}{2}e^{-n_p/2}$	40	40
FSK	Preamplified Direct detection	$= \frac{1}{2}e^{-n_p/2}$	40	40
ASK (OOK)	Heterodyne Synchronous	$= Q\left(\sqrt{n_p/2}\right)$	72	36
ASK (OOK)	Preamplified Direct detection	$= \frac{1}{2}e^{-n_p/4}$	76	38
ASK (OOK)	Heterodyne Asynchronous	$= \frac{1}{2}e^{-n_p/4}$	80	40

DPSK Modulation & De-Modulation

- Each slot contains an optical pulse with phase = 0 or π. The phase difference between adjacent pulses yields data.
- N DPSK yields N-1 Data bits
  - Each DPSK burst preceded by one "seed" pulse of the proper phase

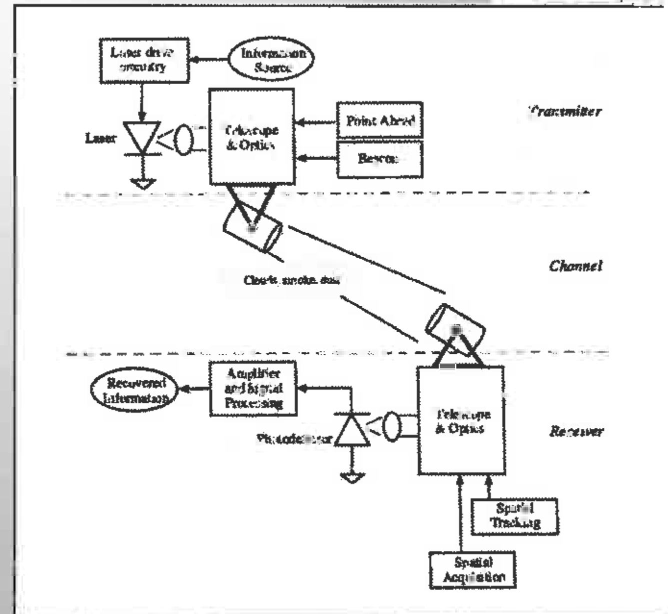


- Data demodulation with optical interferometer



Lasercom leverages advances of Fiber Optic Communication

- No re-amplification along the way (similar to early Metro type fiber-Optic systems)
- No fiber – no dispersion (sort-off)
  - Dispersion in refractive optics of telescope which limits DWDM capability – pointing issue
  - But, in terms of ISI (inter-symbol interference) it is quite advantageous
  - Enables use of large power optical amplifiers
- Biggest concern – Fades
  - Large swings in average power (> 50 dB) which can last up to couple tens of microseconds – hundreds of thousands of lost bits at 10 Gbps rate (larger than SONET frame)
  - Receiver has limited dynamic range (~ 20 dB)
  - Inteleave shall be deep enough to "ride" through fades – > 1 sec interleaver is a must
  - Clock Recovery shall be capable to avoid "slips" during fades
  - Cascading EDFAs in pre-amplified receiver creates pseudo-Automatic Gain Control
    - Holds input power to detector constant
    - ASE noise is fades dependent
    - Can be cleaned with FEC



Lunar Lasercom Aperture

Laser Communications and Space Internetworking Benefits

- Communications Technology Goal: Minimize constraints on future missions imposed by communications and navigation systems
  - Increased data rates
  - Reduced size, weight, and power
  - Increased communications access and capacity
  - Reduced operational complexity
- Laser Communications will provide orders of magnitude increases in data rates with reductions in system size, weight, and power with respect to Radio Frequency (RF) systems
- Space Internetworking/Disruption Tolerant Networking (DTN) provide increased communications access and capacity by allowing more efficient use of available links while also providing scalability
- The LCRD Mission will perform demonstrations of these technologies to move them towards full operational readiness

TDRSS-LIGHT study (circa 1994)

LASER COMMUNICATIONS RELAY DEMONSTRATION

National Aeronautics and Space Administration

NASA

Abstract

Proceedings of SPIE -- Volume 2123
Free-Space Laser Communication Technologies VI, G. Stephen Mecherle, Editor, August 1994, pp. 178-187

Options for selected Articles

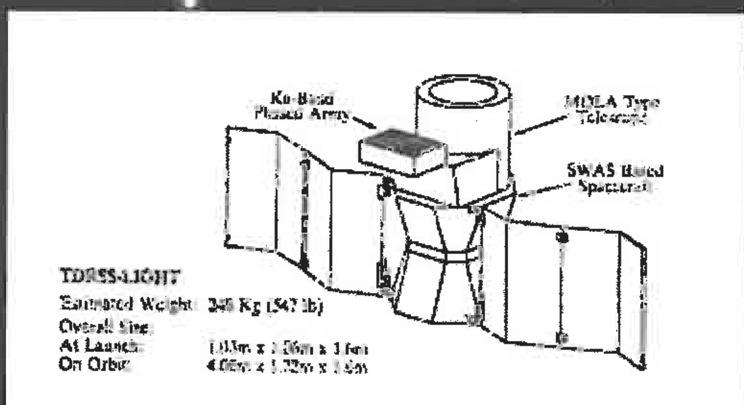
Choose an action | Go

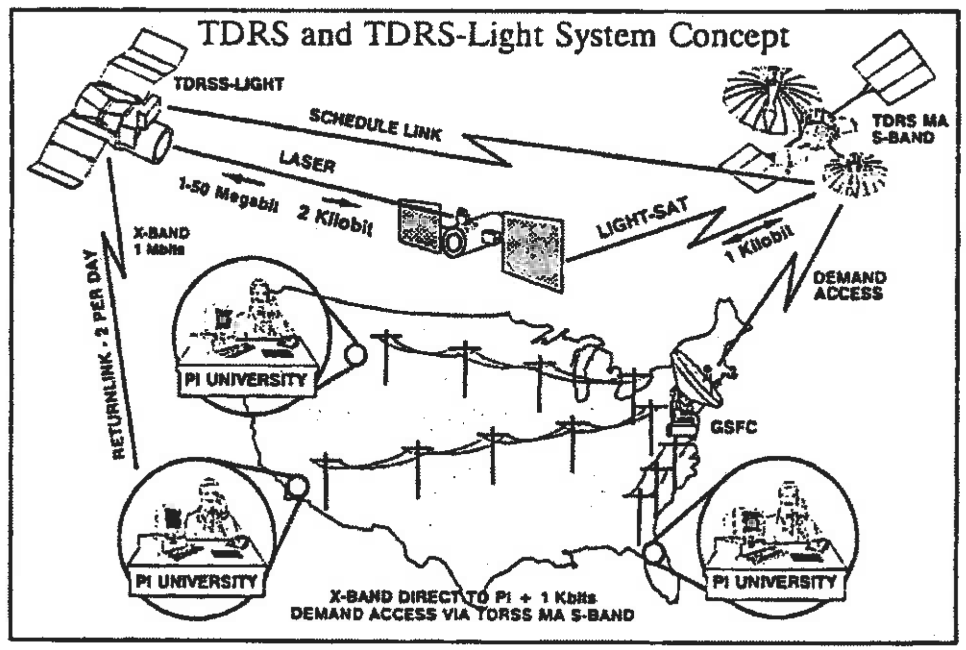
Full Text: [PDF (411 kB)]

Tracking and Delay Relay Satellite System (TDRSS)-LIGHT: a space communications architecture

Bernard D. Seery, Michael W. Fitzmaurice, William L. Hayden, Joseph Burt, Peter O. Minott, and Michael A. Krainak
NASA Goddard Space Flight Ctr. (USA)

There is a growing interest in applying the resources of the Tracking and Data Relay capability for future small satellite users. This interest is based on a variety of benefi globally-distributed space-ground links. An architecture based on an optical augment discussed, including a candidate design for the user and relay terminals.





GSFC (pre-1990) History
1970 - 1977

PROCEEDINGS OF THE IEEE, VOL. 65, NO. 2, FEBRUARY 1977 221

CO_2 Laser Communication Systems for Near-Earth Space Applications

JOHN H. McELROY, SENIOR MEMBER, IEEE, NELSON McAVOY, EDWARD H. JOHNSON, MEMBER, IEEE, JOHN J. DEGNAN, FRANK E. GOODWIN, MEMBER, IEEE, D. MICHAEL HENDERSON, MEMBER, IEEE, THOMAS A. NUSSMEIER, LYLE S. STOKES, BERNARD J. PEYTON, SENIOR MEMBER, IEEE, AND THEODORE FLATTAU, MEMBER, IEEE

- EARLY SPECULATION **on the applicability of lasers** to space communications concentrated on **deep-space missions** (see, e.g., [11-[4]). In the latter half of the 1960's it became evident that the more important E EARLY SPECULATION on the applicability of lasers to space communications concentrated on deep-space missions (see, e.g., [11-[4]). In the latter half of the 1960's it became evident that the more important application was to near-Earth missions, particularly in support of remote sensing applications [51, [6) . By that tinle the technology of terrestrial CO2 laser communication links had advanced to the point where the basic parameters were known and a credible argument could be made for system feasibility [71 -[91 . After an attempt to fly a laser communications system on the ATS-F satellite was cancelled because of budget constraints, a systematic development program was initiated with the objective of removing all possible uncertainties before again committing resources to a flight experiment. This program was begun in1970 and the results are described here.

Free space laser communication experiments from earth to the Lunar Reconnaissance Orbiter

Paper 8246-16 of SPIE Photonics West Conference 8246

Date: Wednesday, 25 January 2012

Author(s): Xiaoli Sun, David R. Skillman, Ronald S. Zellar, Gregory A. Neumann, Leva McIntire, Evan D. Hoffman, David E. Smith, NASA Goddard Space Flight Ctr. (United States); Maria T. Zuber, Massachusetts Institute of Technology (United States)

Free space laser communication experiments were conducted between the satellite laser ranging (SLR) station at NASA Goddard Space Flight Center and the Laser Ranging (LR) receiver on the Lunar Reconnaissance (LRO) over a 380,000-km distance in May 2011. The laser pulse trigger times were modulated by a 1024-ary pulse position modulation (PPM) signal centered in the LR range gate interval. The received signal showed an 80% PPM word detection rate, which was typical for laser ranging measurements through atmosphere under a clear sky condition. More experiments are scheduled later in 2011 with 4096-ary PPM format and error correction coding.

NASA-Goddard Space Flight Center: Lasercom history and past/present synergy with space laser instruments

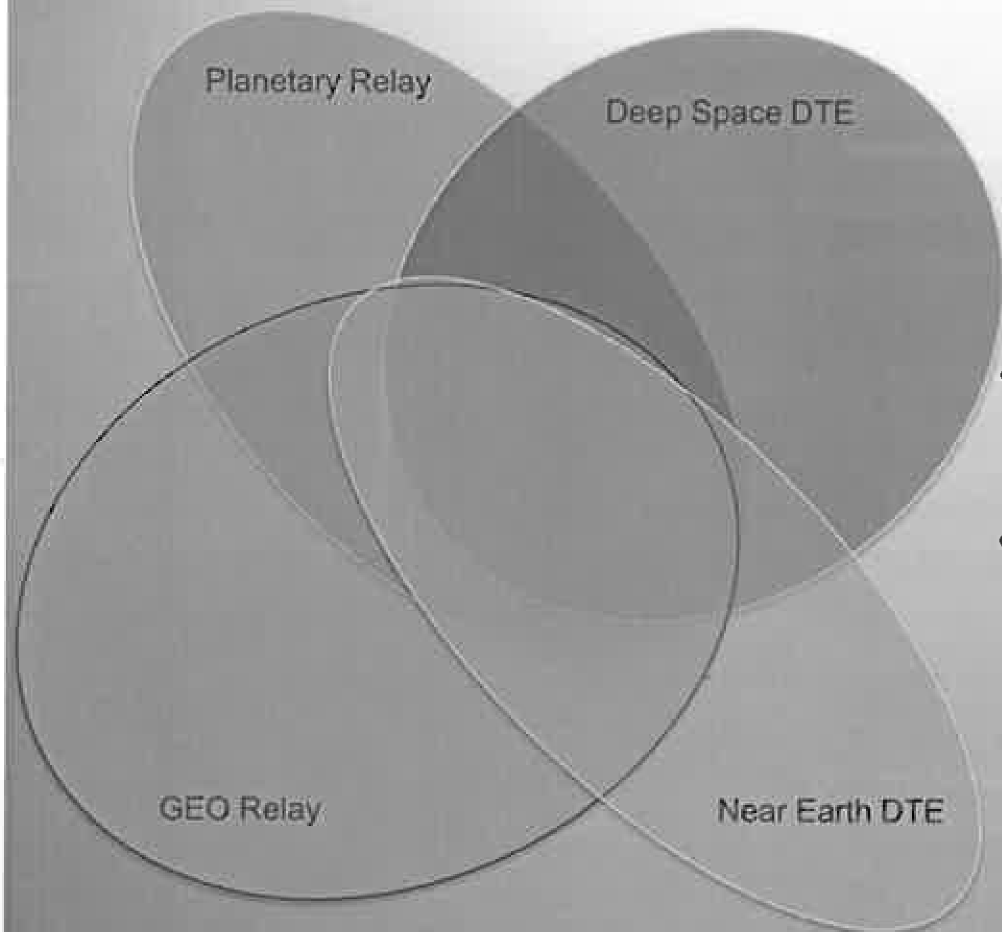
SUMMARY

- NASA-GSFC has a rich history of space laser communications projects from the 1960s to the present.

- Space flight lidars have been NASA-GSFC **in-house** laser instrument focus for the past two decades with great success.

- Laser transceiver, pointing/tracking, optics and high speed electronics technologies (required for LCRD) are synergistic with present and upcoming lidar experience and technologies.

Infusion Targets



*Notional Diagram not to scale or meant to be all inclusive

- Technology Demonstration Mission (TDM) is an opportunity to do as much for as many different applications as possible, but cannot do everything for everybody
  - Cost/schedule/complexity/risk
  - Physics and geometry
- The primary infusion target is the Next Generation Tracking and Data Relay Satellite (TDRS)
- LCRD moves beyond "does the technology work?" and focuses on "how does one fully utilize lasercom and networking technology?"
  - Network, ground, and flight architectures
  - Operations concepts refinement
  - Requirements development
  - Performance characterization and model validation

Project Overview

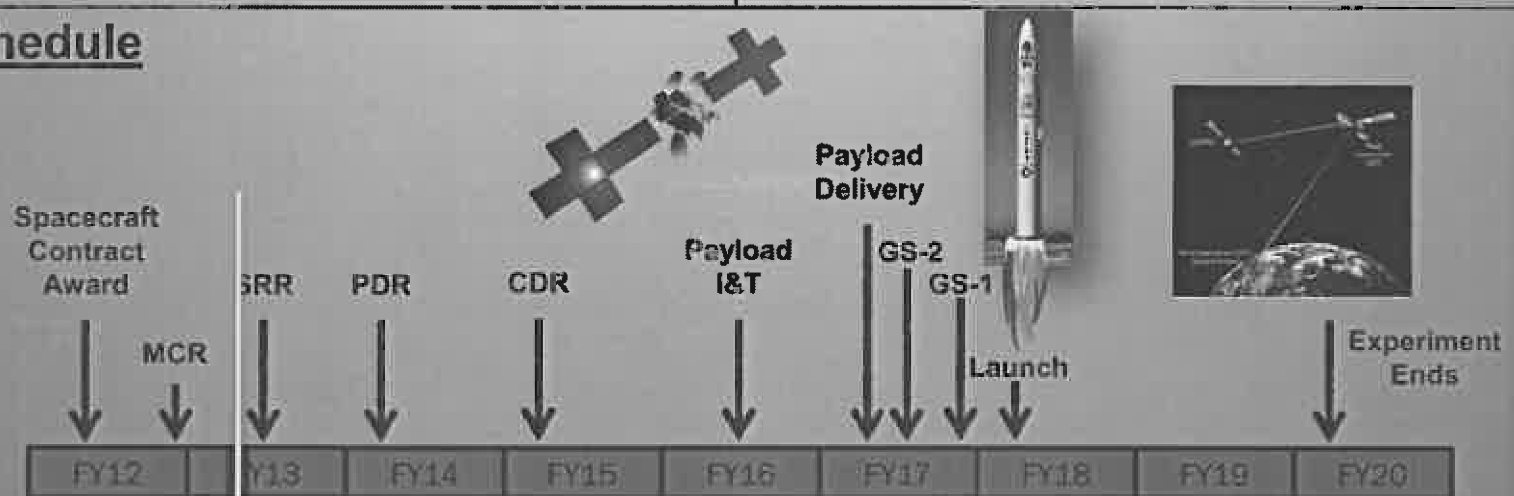
Technology Objectives

- Demonstrate optical communications relay services between GEO and Earth to enable future optical communication systems and relay networks
- Provide the necessary operational experience to guide NASA in developing an architecture and concept of operations for a future optical based network
- Demonstrate networking protocols including DTN onboard Payload at target data rates applicable to Mars or L1/L2 relay trunk lines

Mission Concept

- Orbit: Geosynchronous
  - 162°W to 63°W Longitude
- 2 years mission operations
- 2 operational GEO OMs
- 2 operational Optical Earth Terminals
- Ability to support a LEO User
- Hosted Payload
- Launch Date: Dec 2017

Schedule

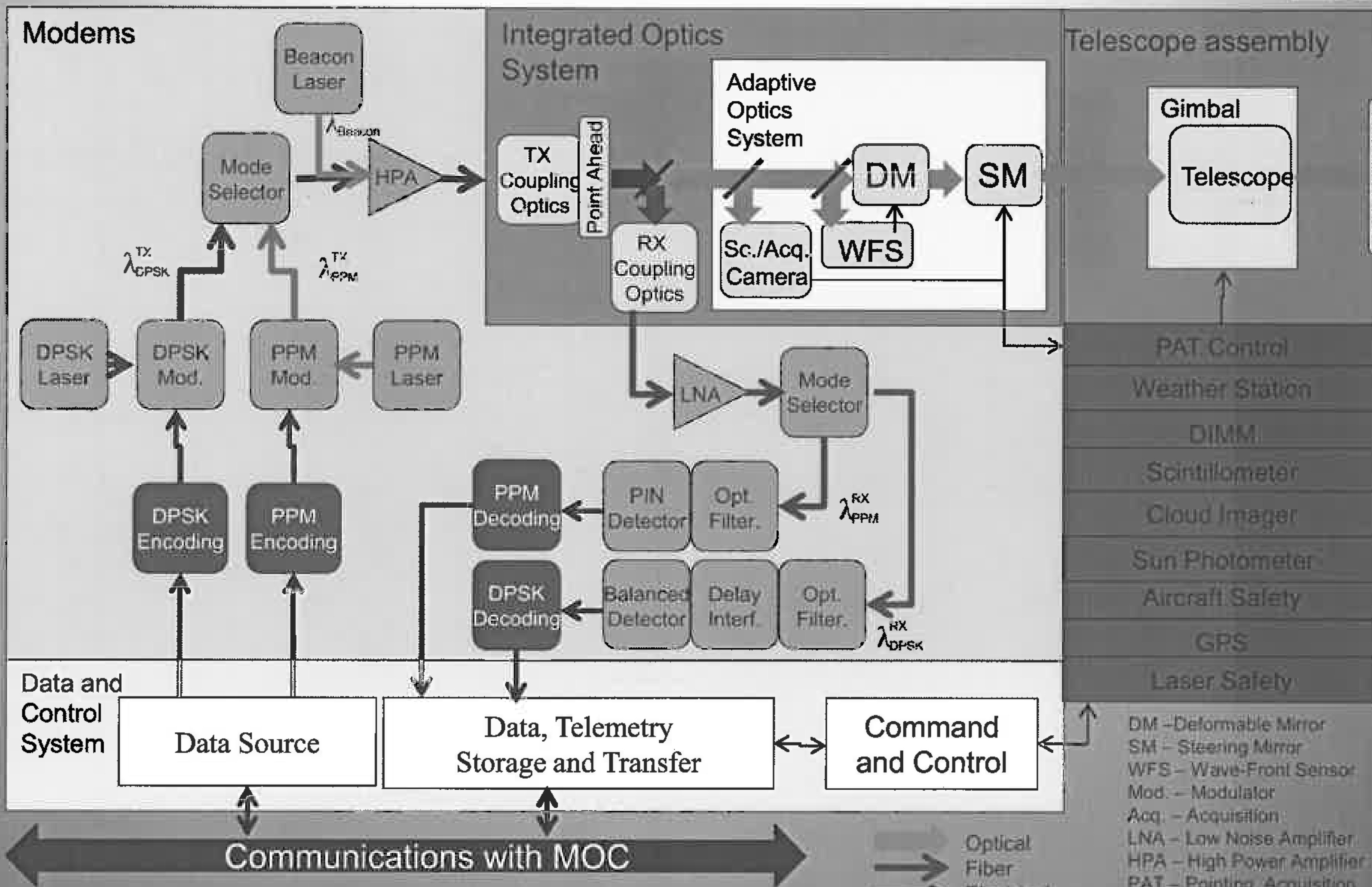


Optical Communication Modem Functionality

- Optical communication modem provides following functionalities to the system
  - Generates and detects optical signals
  - Modulates and De-modulates optical signals (Mo-Dem)
  - Encodes and Decodes Error Correction and Interleaving (only on ground station for LCRD)
  - Boosts and pre-amplifies optical signals
  - Shapes optical signals and filters background noise
- There are no decisions being made in the modem
  - It is controlled by external controller
  - Few analog control loops

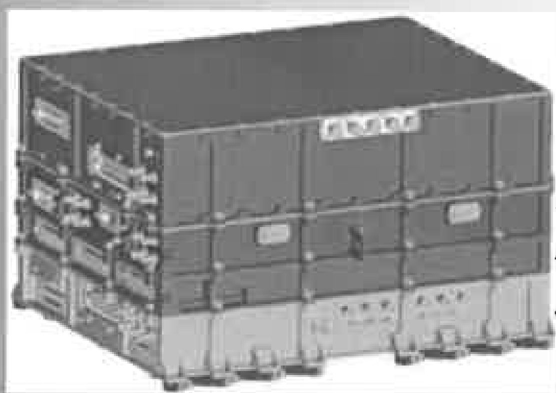
Modem is a "heart" of the Optical Terminal

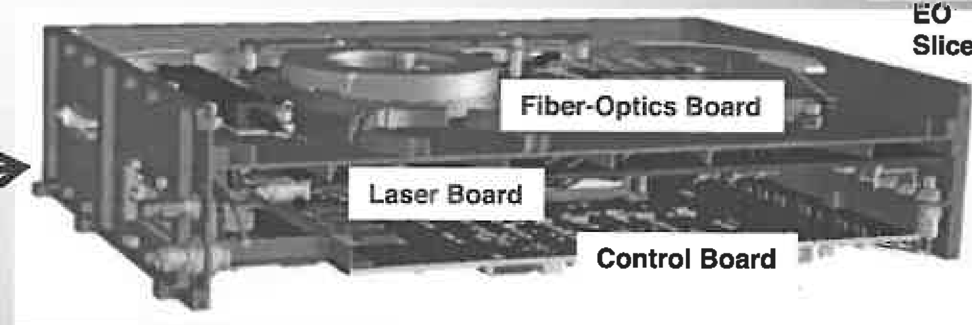
(Ground Terminal Example)

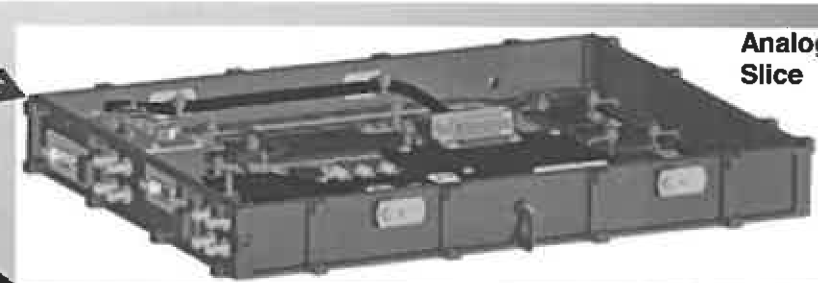


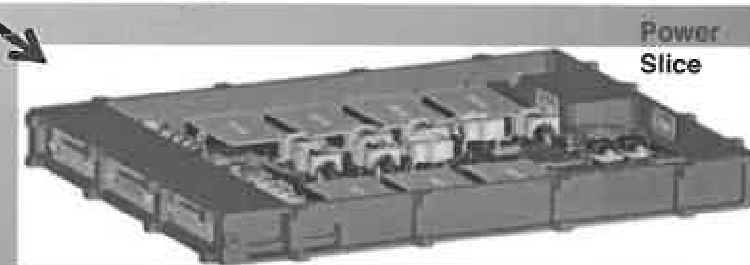
Detailed View of PPM Modem (LLCD Design)

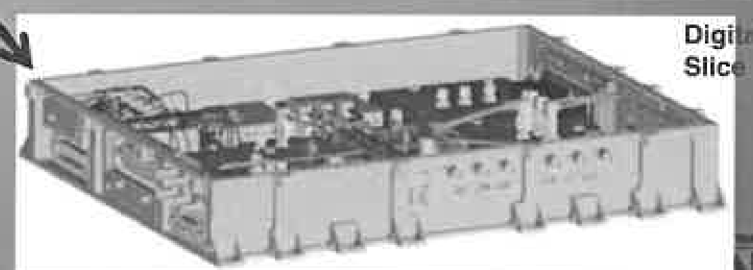
PPM Modem





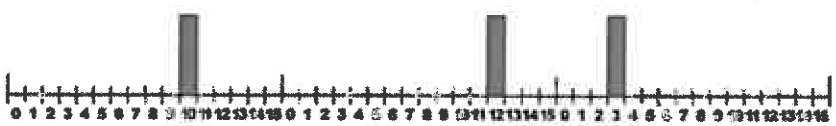




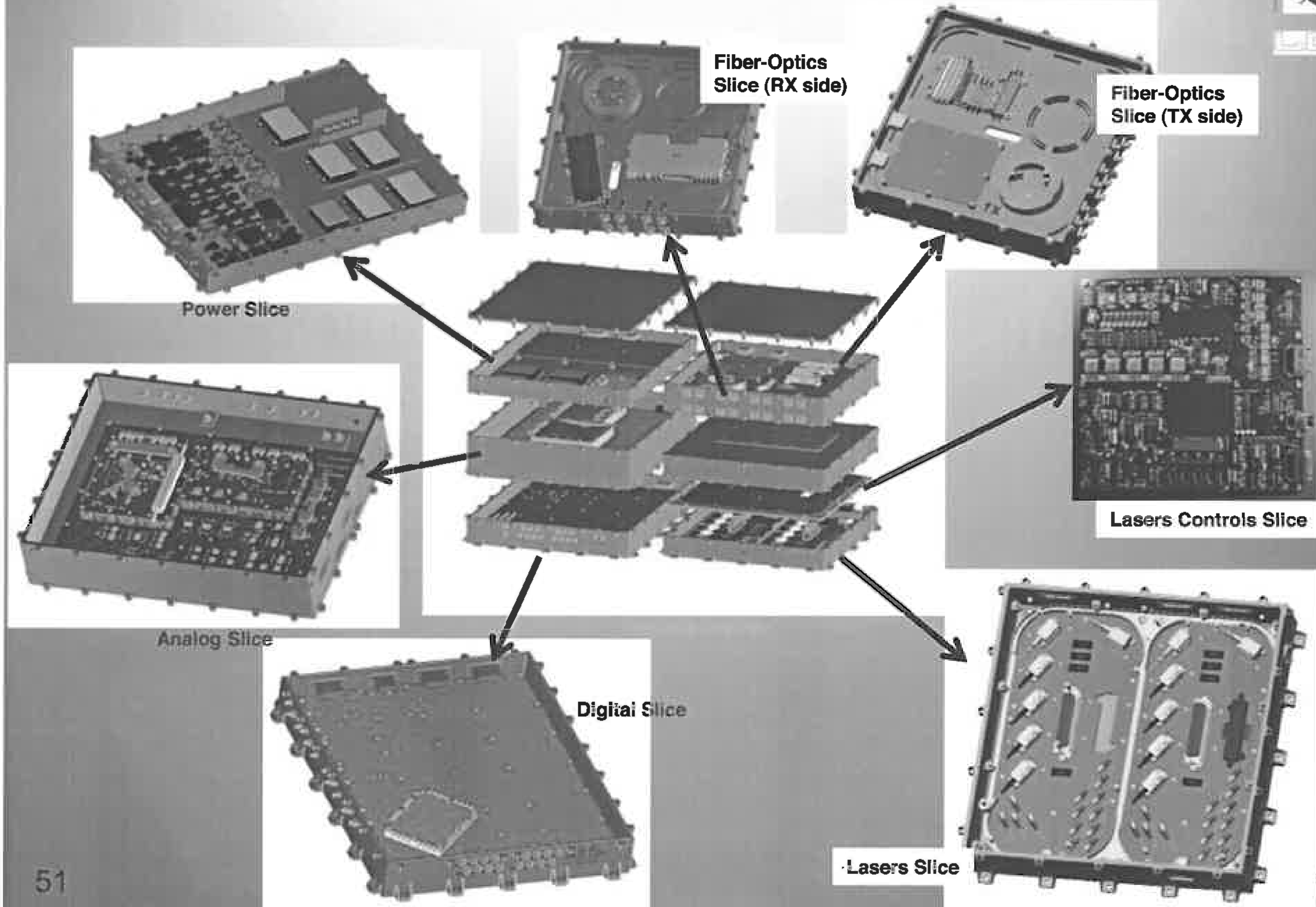


- M message bits are encoded by transmitting a single pulse in one of 2^M possible time slots. It is repeated every T seconds such that the transmitted bit rate is M/T bps
- Lasercom Downlink
  - 16 PPM
  - Data rate varied by changing slot rate (0.311 – 5GHz)
- Lasercom Uplink
  - 4-PPM with dead time
  - Fixed slot rate, 311 Mslot/s
  - Data rate varied by changing dead time (12 or 28 slots)

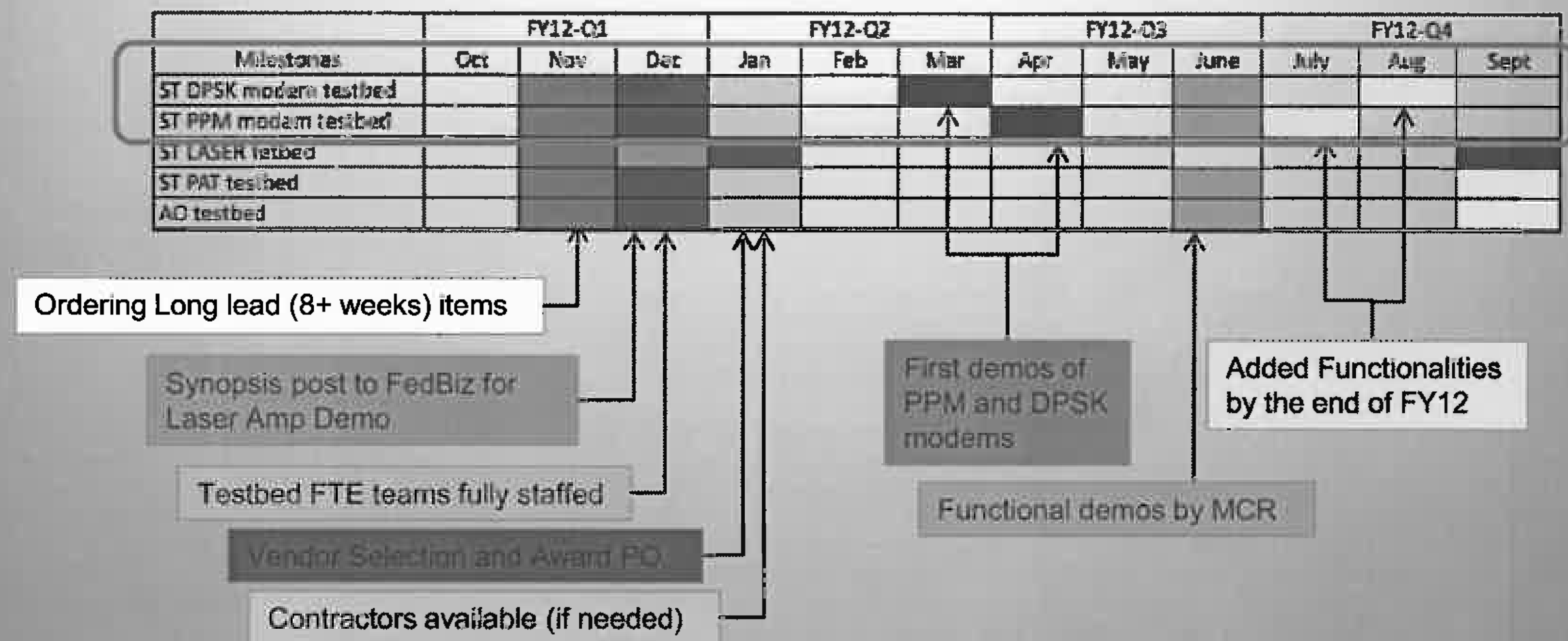
PPM Waveform



Detailed View of DPSK Modem



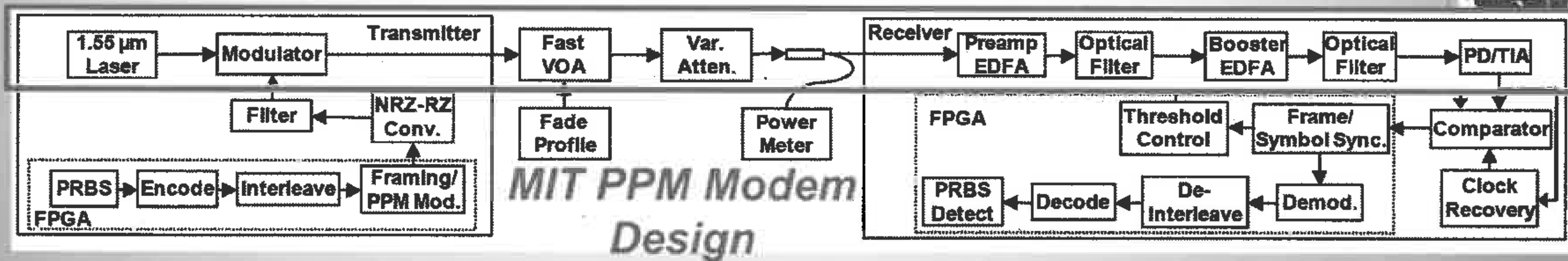
Breadboards Planed Development in FY12



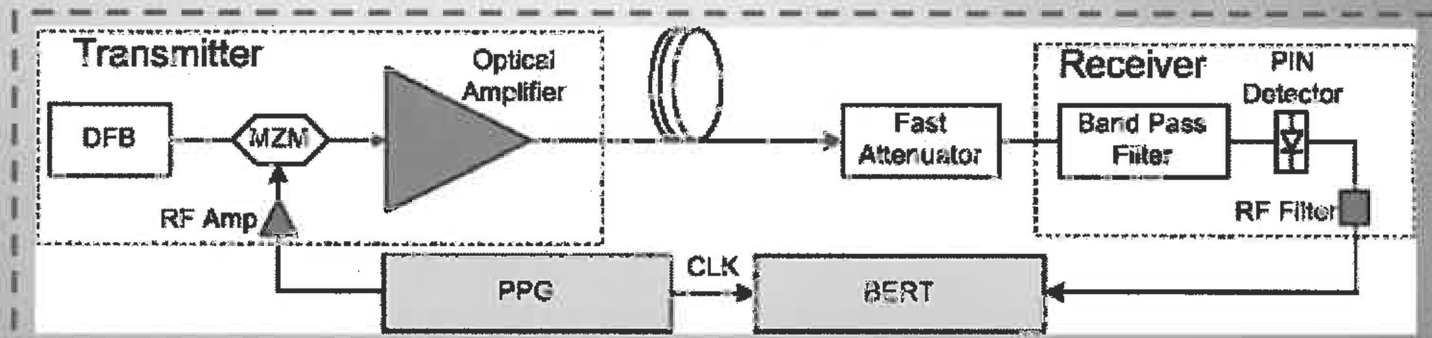
Assumptions:

1) Build DPSK and PPM prototypes from COTS parts with performance 10 dB worse than MIT/LL
2) DPSK and PPM prototypes performance 10 dB off that of MIT/LL
3) Use MIT/LL PPM and DPSK modem designs as guidance
4) Labs and test equipment are available
5) Contractor support is available if needed
6) Procurement process is less than 12 weeks for any part
7) FTE manpower support is available immediately
8) Receive adequate information on DPSK modem

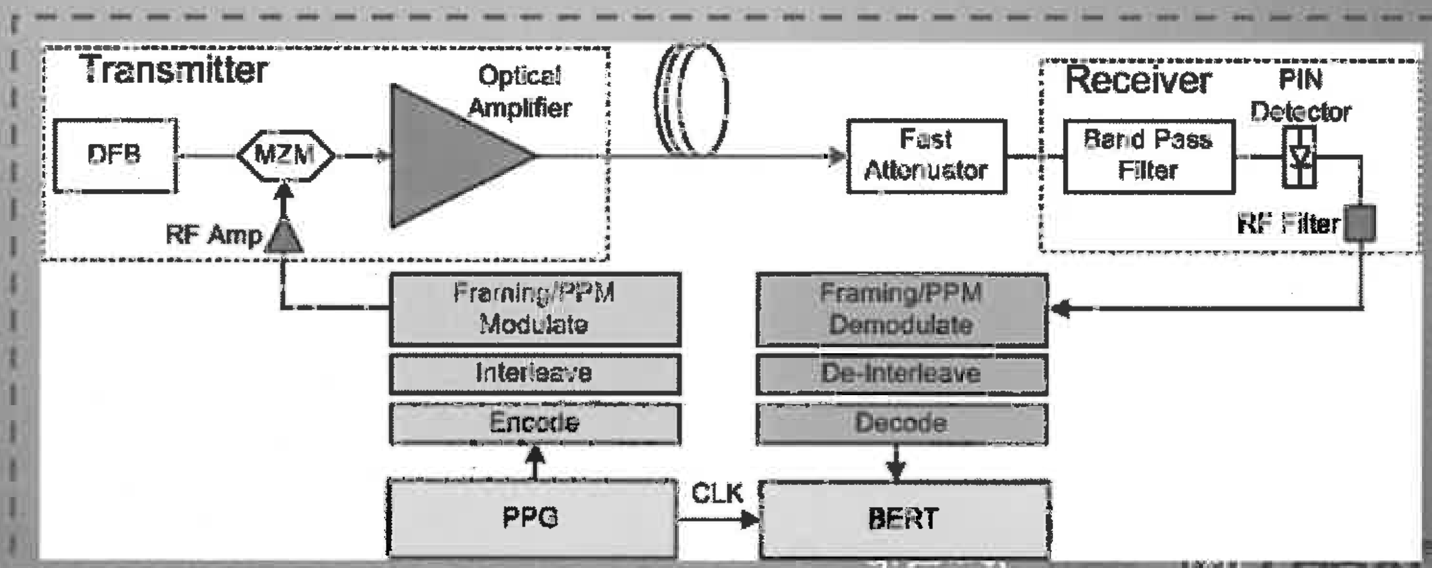
LCRD Testbeds: PPM



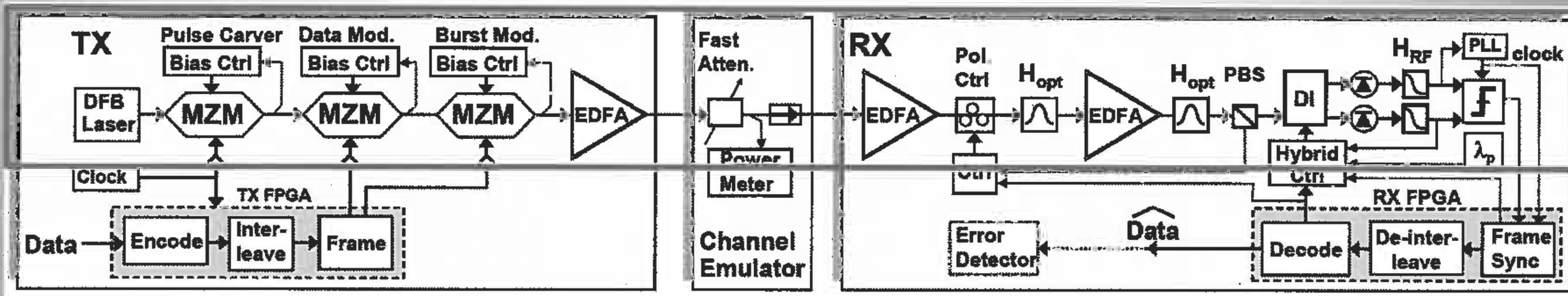
STEP-1
Build Simplified system



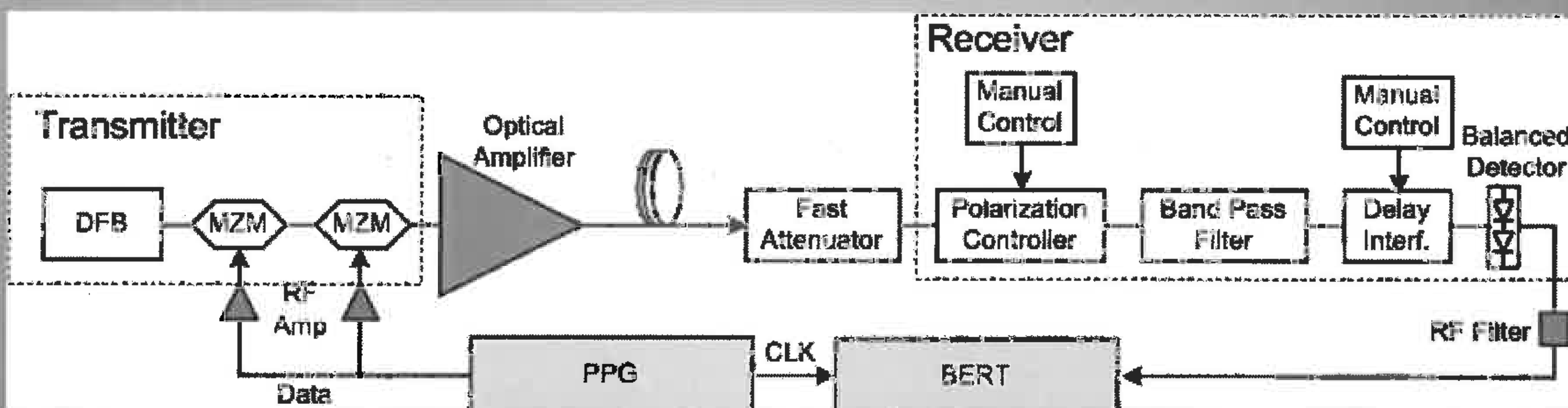
STEP-2
Incorporate newly developed electronic boards



LCRD Testbeds: DPSK

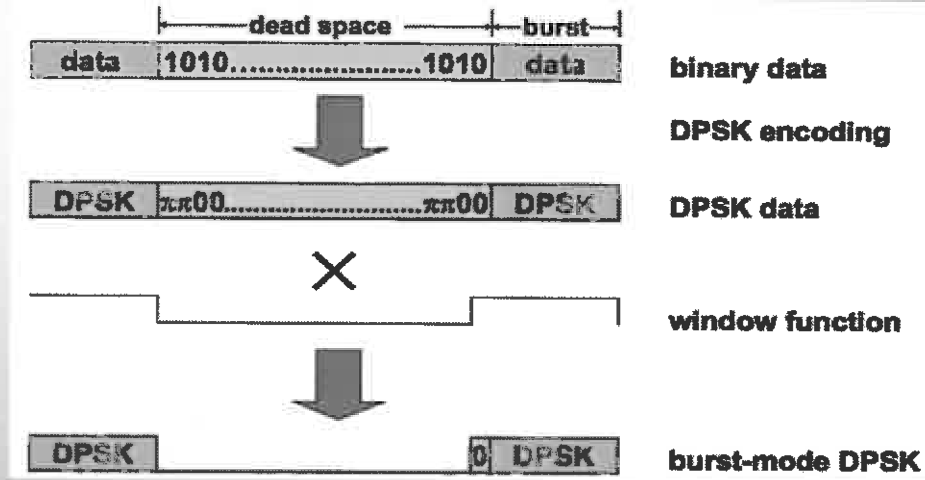


MIT DPSK Modem

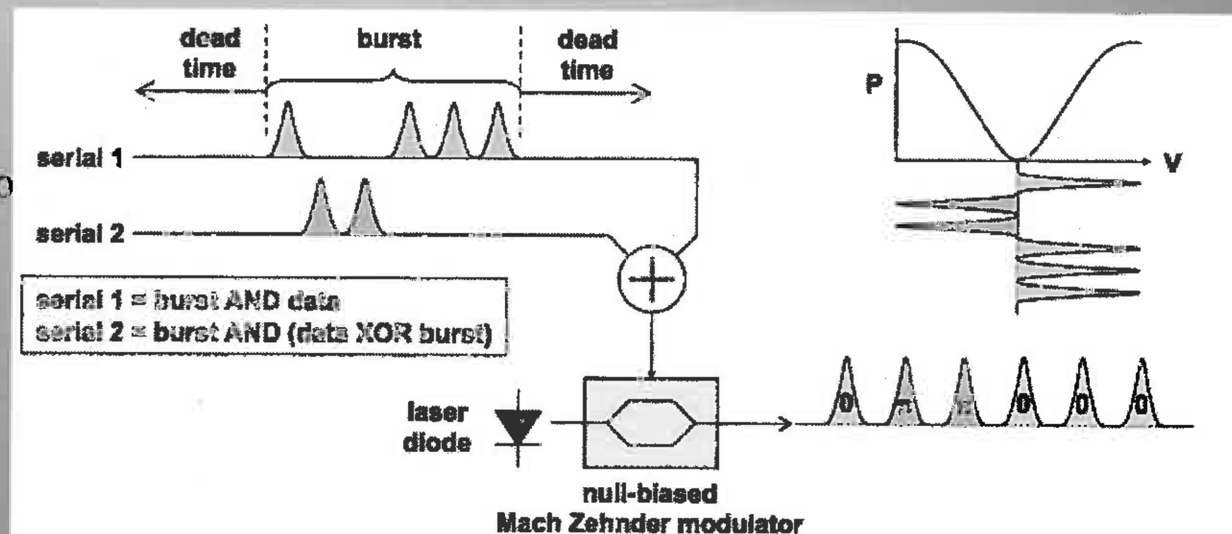


DPSK Trinary State Burst Modulation

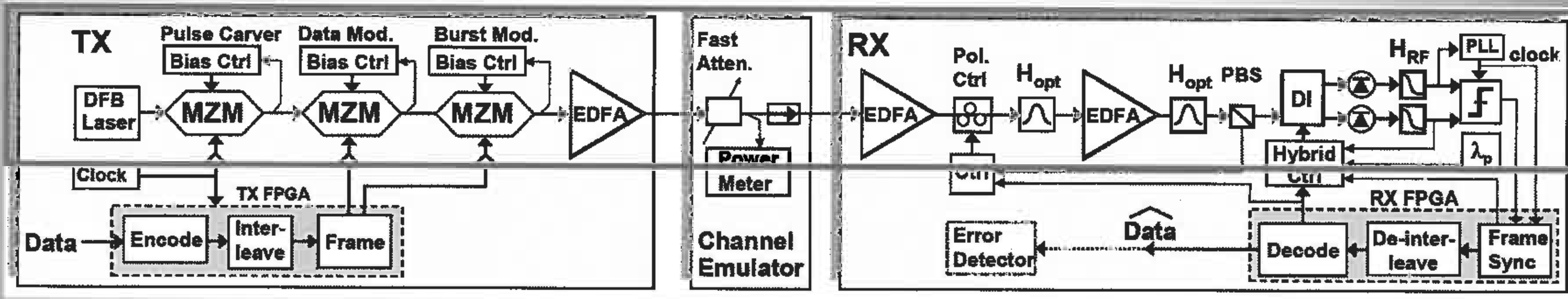
- Typical DPSK Optical Modulation requires 3 modulators
  - Pulse Carver
  - Data Modulator
  - Burst Modulator



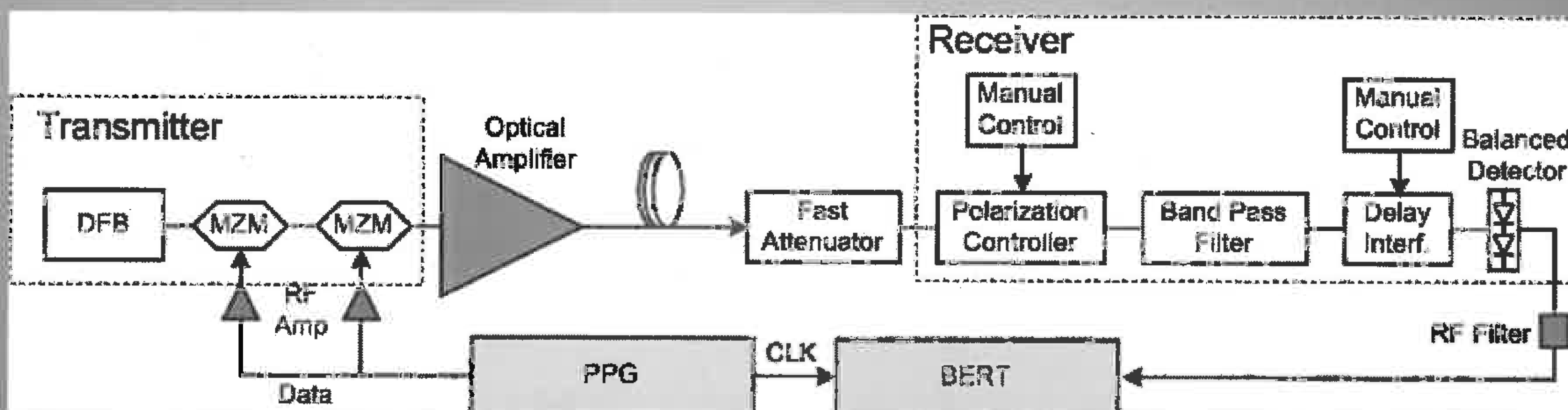
- LCRD DPSK Optical Modulation requires 1 modulator
  - Generate 3-level DPSK waveform (electrically)
  - DPSK data and burst windo mapped to two bursty unipolar streams
  - Mapping requires combinatorial FPGA logic (constantly-updated flip-flops)



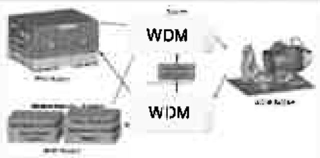
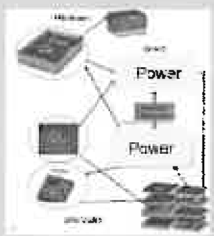
LCRD Testbeds: DPSK



MIT DPSK Modem

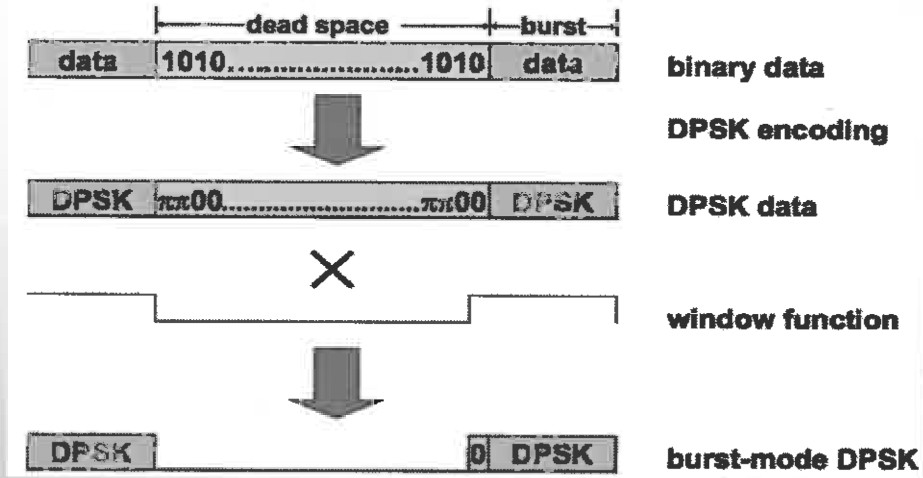


Flight Modems Combining options Cases Trade-offs

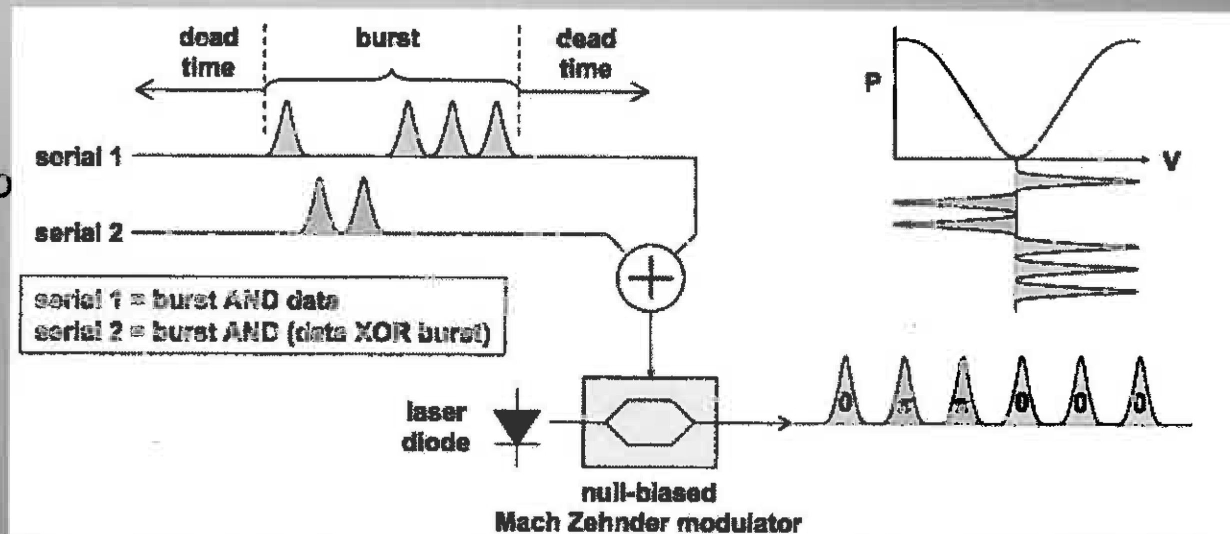
Case	Option	Pros.	Cons.	Rating
1		No change to existing designs required	Extra dB(s) of loss to link budgets	3
2		Transmit and Receive optical power amplifiers redundancy	Additional fiber connectivity between modems	2
3		Single EO slice design: low complexity, low SWAP, low cost	Possible impact to biasing circuitry and control	1

DPSK Trinary State Burst Modulation

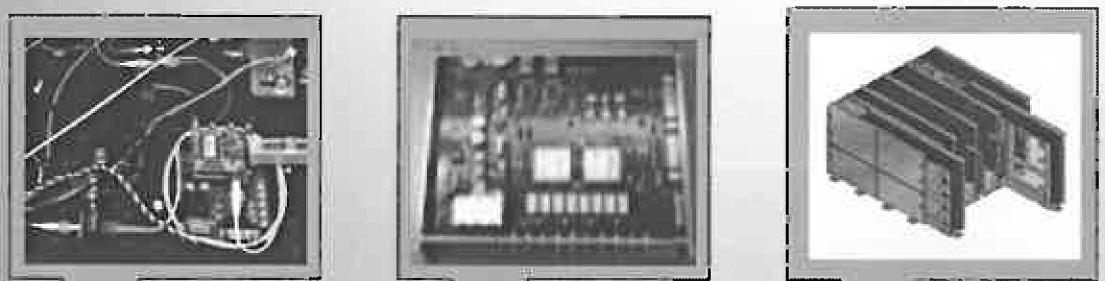
- Typical DPSK Optical Modulation requires 3 modulators
  - Pulse Carver
  - Data Modulator
  - Burst Modulator



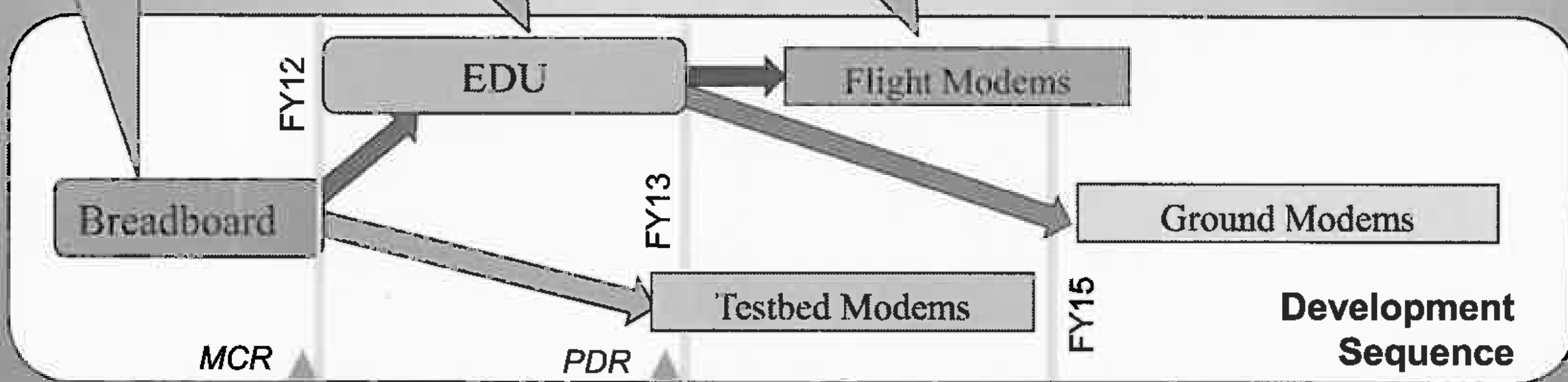
- LCRD DPSK Optical Modulation requires 1 modulator
  - Generate 3-level DPSK waveform (electrically)
  - DPSK data and burst windo mapped to two burst unipolar streams
  - Mapping requires combinatorial FPGA logic (constantly-updated flip-flops)



LCRD Modems Development Flow
(EDUs recycled for Ground Modems)



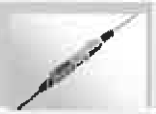
- EDU 9/2013 (3 units)
- FLT 8/2014 (2 units)
- Update EDUs for GRD 9/2016 (2 units)



Objective Performance

Modem	Threshold (by MCR)	Goal (by PDR)
DPSK	14 dB ph/b @ 1e-3	11 dB ph/b @ 1e-3
PPM*	12 dB ph/b @ 1e-3	9 dB ph/b @ 1e-3

EO Components Selected based on MITLL designs (some modification required to address obsolescence)

Component		Technology	SWAP	TRL
Signal Laser		InGaAsP Distributed FeedBack (DFB) Laser Diode in 14 pin butterfly package	2W(TEC on), ¼ cubic inch	6
Pump Lasers		14 pin butterfly packaged fiber Bragg grating stabilized Laser Diode	3W(TEC on), ¼ cubic inch	6
Optical Modulator		Lithium Niobate (LiNbO3) X-cut in Mach-Zender configuration		6
Photodetector (DPSK)		InGaAs diode pair in balanced configuration	½ W, ½ cubic inch	4
Photodetector (PPM)		InGaAs PIN	¼ W, ¼ cubic inch	6
Booster Optical Amplifier		Double-Clad Erbium-Ytterbium doped fiber amplifier	NA	5
Optical Pre-Amplifier		Low noise figure Erbium doped fiber amplifier	NA	5
Delay Interferometer		Lithium Niobate (LiNbO3) X-cut in Mach-Zender configuration with one bit delay at maximum data rate. Delay length precisely controlled with thermo-electric cooler	½ W (TEC on), ½ cubic inch	4
Optical Filter		Fiber Bragg Grating filter with thermal control	½ W, ½ cubic inch	4

* All components are fiber pigtailed